

**Mechanical workload and neck and shoulder pain
at the start of working life**

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CONTENTS

ACKNOWLEDGEMENTS	5
SUMMARY	7
SAMMENDRAG	9
LIST OF PUBLICATIONS	11
BACKGROUND	13
Musculoskeletal disorders.....	14
Work-related neck and shoulder pain.....	15
Mechanical workload	19
Self-reported mechanical workload (Paper I)	20
Trapezius muscle activity during work (Paper II)	21
Arm elevation during work (Paper III).....	22
How can mechanical workload influence neck and shoulder pain?	23
Young workers.....	26
STUDY OBJECTIVES	30
METHODS	31
Study design	31
Subjects	33
Data collection.....	36
Questionnaire.....	36
Clinical examination	39
Technical measurements	39
Missing data	44
Data processing and statistical analyses	47

Imputation.....	47
Statistical analyses.....	48
RESULTS IN SUMMARY	50
Paper I	50
Paper II	52
Paper III	54
Supplementary analyses	56
DISCUSSION	61
Methodological considerations.....	61
Reflections regarding the internal validity	62
Reflections regarding the external validity	69
Discussion of main findings	73
Reflections on variables associated with neck and shoulder pain.....	74
CHALLENGES FOR FUTURE RESEARCH	82
CONCLUSIONS	84
REFERENCES	86

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SUMMARY

Background: Musculoskeletal pain is prevalent both in adolescents and in the general working population. The neck and shoulder region is most commonly affected. Mechanical workload such as work in awkward postures, sustained work with hands above shoulder level, heavy lifting and repetitive work have previously been acknowledged as risk factors in adult working populations. The results have mainly been based on self-reported exposure data and the duration and intensity of the exposure is often disregarded. Young workers report more mechanical work exposures than older workers and the prevalence of musculoskeletal pain among young adults is increasing. It has however been very few studies investigating the mechanical workload as a risk factor for neck and shoulder pain among young workers.

Objective: This dissertation focuses on neck and shoulder pain in a cohort of young adults during their transition from technical school to working life. The aim was to explore the relationship between mechanical workload and neck and shoulder pain, using three different measures of work exposure.

Methods: The cohort consisted of 420 technical school students (representing student hairdressers, student electricians and media/design students) from the greater Oslo area. They were followed over a 6.5 year period from technical school into working life. Every 4th month during the study period neck and shoulder pain was assessed by questionnaire. Approximately halfway in the follow-up period, a technical field measurement was performed assessing the mechanical workload objectively on a subsample of 43 subjects. *Paper I* included the entire cohort that was followed 6.5 years. The mechanical workload was assessed by questionnaire approximately twice a year in the follow-up period. *Paper II* was based on the subsample. Surface electromyography on the upper trapezius muscle was measured during a whole working day. The relative time with sustained muscle activity for periods lasting >4minutes was used in the analyses. The neck and shoulder pain was assessed every 4th month during 2.5 years of follow-up. *Paper III* was also based on the subsample. Mechanical workload was measured using bilateral inclinometers on the upper arms. The relative time of work with prolonged arm elevation >60° and >90° were used in the analyses. The shoulder pain was assessed by pain drawings every year during the 2.5 year follow-up.

Results: An increase in neck and shoulder pain among young workers during their transition from technical school to working life was found. The pain severity levels reported were however relatively low, especially among men. *Paper I* showed that self-reported mechanical workload was associated with neck and shoulder pain. Stratifying by gender the association was significant among women. Perceived muscle tension was associated with neck and shoulder pain in both genders while clinically tested shoulder muscle endurance was negatively associated with neck and shoulder pain among men. In *Paper II* the results showed that high levels of sustained trapezius muscle activity during work was associated with neck and shoulder pain. *Paper III* showed that time with prolonged arm elevation $>60^\circ$ was associated with shoulder pain, however only significant among women.

Conclusions: The main conclusion from the three papers in this dissertation was that both self-reported and objectively measured mechanical workload was associated with neck and shoulder pain in the first years of working life, especially among women. The objectively measured sustained muscle activity during work and perceived muscle tension was associated with neck and shoulder pain in both genders. It was also evident from this dissertation that the neck and shoulder pain increases during the transition from technical school to working life. Even though the reported pain severity levels were relatively low, the findings suggests that mechanical workload is a risk factor already early in working life. This may indicate the need for attention on the work environment among young workers particularly those in manual working environments.

SAMMENDRAG

Bakgrunn: Muskel- og skjelettsmerter er utbredt både blant ungdom og i den generelle yrkesaktive befolkningen. Høyest smerte forekomst finner man i nakke- og skulderregionen. Mekanisk arbeidsbelastning som arbeid i ubekvemme stillinger, vedvarende arbeid med hendene over skulderhøyde og ensformig arbeid er alle anerkjent som risikofaktorer hos middelaldrende og eldre arbeidstakere. Tidligere studier har imidlertid ofte vært basert på selvrapporterte mål av mekanisk arbeidsbelastning uten å ta eksponeringens varighet og intensitet i betraktning. Unge arbeidstakere rapporterer mer mekaniske arbeidseksponeringer enn eldre arbeidstakere og man finner en økende forekomst av muskel- og skjelettsmerter blant unge voksne. Det er imidlertid få studier som har undersøkt mekanisk arbeidsbelastning som risikofaktor for nakke og skuldersmerter blant unge arbeidstakere.

Formål: Denne avhandlingen setter fokus på nakke- og skuldersmerter blant unge voksne i overgangen fra yrkesfaglig utdanning til arbeidsliv. Målsettingen var å undersøke relasjonen mellom mekanisk arbeidsbelastning og nakke- og skuldersmerter, ved bruk av tre forskjellige eksponeringsmål.

Metoder: Studiekohorten besto av 420 elever fra yrkesfaglig utdanning hvor yrkesprogrammene frisør, elektriker og media/design var representert. Elevene var alle fra skoler i Oslo-området. Deltagerne ble fulgt over en 6,5 års periode fra yrkesfaglig utdanning, via lærlingtid og videre ut i arbeid. Hver fjerde måned gjennom oppfølgingsperioden ble nakke- og skuldersmerter rapportert ved hjelp av spørreskjema. Halvveis i oppfølgingsperioden ble det gjennomført en teknisk feltmåling av den mekaniske arbeidseksponeringen på en subpopulasjon bestående av 43 deltagere. *Artikkel I* er basert på hele utvalget fulgt i hele studieperioden. Mekanisk arbeidsbelastning ble vurdert ved hjelp av spørreskjema ca. 2 ganger i året i hele perioden. *Artikkel II* baserte seg på subpopulasjonen, hvor overflate electromyografi (sEMG) på øvre kappemuskel (m. trapezius) ble målt gjennom en hel arbeidsdag. Eksponeringen ble definert som den relative tid av arbeidsdagen med vedvarende muskelaktivitet med varighet >4minutter. Nakke- og skuldersmerter ble rapportert hver 4 måned under oppfølgingsperioden på 2.5 år. *Artikkel III* baserte seg også på subpopulasjonen, og armelevasjon under arbeid ble målt ved hjelp av inklinometri på

overarmene. Den relative tiden av arbeidsdagen med vedvarende armelevasjon $>60^\circ$ og $>90^\circ$ ble analysert. Skuldersmerter ble rapportert ved spørreskjema hvert år over oppfølgingsperioden på 2.5 år.

Resultater: Resultatene viser en økning av nakke- og skuldersmerter blant unge voksne i overgangen fra yrkesfaglig utdanning til arbeidsliv. Det rapporterte smertenivået var allikevel relativt lavt, spesielt for menn. *Artikkel I* viste at selvrapportert mekanisk arbeidsbelastning var assosiert med nakke- og skuldersmerter. Stratifisert for kjønn var assosiasjonen signifikant for kvinner. Selvrapportert muskelspenning var assosiert med nakke- og skuldersmerter for begge kjønn, mens klinisk testet utholdenhet i skulder var en beskyttende faktor for nakke- og skuldersmerter for menn. I *artikkel II* viste resultatene at å arbeide med vedvarende trapezius muskelaktivitet var assosiert med nakke- og skuldersmerter. *Artikkel III* viste at å arbeide med langvarig armelevasjon med vinkler $>60^\circ$ var assosiert med skuldersmerter, spesielt blant kvinner.

Konklusjoner: Hovedkonklusjonen fra de tre artiklene var at både selvrapportert mekanisk arbeidsbelastning og objektivt målt arbeid med armene hevet var assosiert med nakke- og skuldersmerter de første årene av arbeidslivet, spesielt blant kvinner. Resultatene viser også at vedvarende muskelaktivitet under arbeid og selvrapportert muskelspenninger var assosiert med nakke- og skuldersmerter. Det er også tydelig fra denne avhandlingen at nakke- og skuldersmerter øker i overgangen fra yrkesfaglig utdanning og inn i arbeidslivet. De rapporterte smertenivåene er imidlertid relativt lave. Funn fra denne avhandlingen indikerer at mekanisk arbeidsbelastning er en risikofaktor også tidlig i arbeidslivet og viser et behov for oppmerksomhet på arbeidsmiljøet blant unge arbeidstakere, spesielt innen manuelle yrker.

LIST OF PUBLICATIONS

The dissertation is based on the following three publications:

Paper I:

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Twisk J, Veiersted KB.

A longitudinal study on risk factors for neck and shoulder pain among young adults in the transition from technical school to working life.

Scand J Work Environ Health. 2014 May 23. [E-pub] Online-first article.

Paper II:

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Stigum H, Twisk J, Veiersted KB.

The effect of work-related sustained trapezius muscle activity on the development of neck and shoulder pain among young adults.

Scand J Work Environ Health. 2013;39(4): 390-400.

Paper III:

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Veiersted KB.

Work with prolonged arm elevation as a risk factor for shoulder pain: a longitudinal study among young adults.

Applied Ergonomics. 2015;47: 43-51. Online-first article.



BACKGROUND

In this dissertation the focus was on neck and shoulder pain in a cohort of young adults during their transition from technical school to working life. The overall aim was to identify early risk factors for neck and shoulder pain among these young adults with special emphasis on mechanical workload. The background for this aim was based on the awareness that musculoskeletal disorders are afflicting a substantial proportion of the general and working population in the Western world. Musculoskeletal disorders are the greatest cause of disability in Europe and the second greatest worldwide (Stewart et al., 2013; Vos et al., 2012). The disorders represent an enormous demand on society with costs of sick leave and lost productivity (Jacobs et al., 2013; van den Heuvel et al., 2007). In addition to the economic burden there is a physical and emotional burden for the individual affected. In Norway it is the largest single cause of sick leave and disability benefits (Lærum et al., 2013) and the expenses related to musculoskeletal disorders in health care and employment has doubled the past 10 years (Lærum et al., 2013). A large amount of research aiming at identifying the risk factors of musculoskeletal disorders among workers has been conducted (Bernard, 1997; Côté et al., 2008; Mayer et al., 2012; Punnett, 2014). It is however a complex picture characterized as multifactorial, meaning that there are several risk factors acting together in the development of musculoskeletal disorders (WHO, 1985). The risk factors include mechanical, psychosocial, individual, behavioral and socio-cultural components (Cagnie et al., 2007; Christensen and Knardahl, 2010; Hamberg-van Reenen et al., 2006b; Luime et al., 2005; Wahlström et al., 2004). Work involving repetitive movements, working with arms elevated and lifting in restricted or twisted positions are all specific mechanical risk factors related to musculoskeletal disorders (da Costa and Vieira, 2010; Mayer et al., 2012; van Rijn et al., 2010). The risk of reporting musculoskeletal pain generally increases with age. In certain occupations with high levels of mechanical workload however musculoskeletal pain is prevalent also at an early age (Woods and Buckle, 2002). Manual workers like electricians and hairdressers are examples of occupations with high mechanical demands, frequently exposed to mechanical risk factors like working with arms elevated (Moriguchi et al., 2013; Veiersted et al., 2008; Wahlström et al., 2010). At the same time these occupational groups show high prevalence of neck and shoulder pain (Boschman et al., 2012; Veiersted et al.,

2008). This was relevant background knowledge when developing the hypotheses and including participants for the papers in this dissertation. According to the statistics from Norway's nationwide survey (SSB, Level of Living: Working Conditions), young workers are more likely to be exposed to poor mechanical working conditions than older workers and they report work-related health problems already at a young age (NOA, 2011). A recent study strongly suggests that factors at the beginning of working life have delayed consequences, especially for workers with musculoskeletal disorders (Leclerc et al., 2014). This underlines the importance of studying populations in the transition from school to working life and the need to evaluate the importance of mechanical workload in relation with the development of musculoskeletal pain early in working life as done in this dissertation.

Musculoskeletal disorders

The Global Burden of Disease Study 2010 (GBD) is one of the largest health studies ever undertaken. It studied 291 diseases and injuries in 21 regions covering the globe and involved nearly 500 researchers in more than 300 institutions in 50 countries. The study emphasizes that there is a continuing global shift from life-threatening diseases as a cause of disability to the commonly disabling chronic disorders like those of the musculoskeletal system and psychological disorders (Stewart et al., 2013). The magnitude of the problem has resulted in increased attention to identify the determinants of musculoskeletal disorders. The worldwide Bone and Joint Decade, is one example, with a mission to reduce the burden of musculoskeletal conditions and to illuminate both the physical and economic costs of these disorders. The worldwide Bone and Joint Decade is an international collaborative movement sanctioned by the United Nations and the World Health Organization. It started out as a mission for a period from 2000-2010, and has now renewed its mandate for another 10 years (2010-2020).

Musculoskeletal disorders constitute a burden in both the general and working population. The Norwegian part of the Bone and Joint Decade published a report in 2013 showing that 40 % of all sick leave and 30 % of all disability pensioners have diagnoses related to musculoskeletal disorders (Lærum et al., 2013). Figures from Statistics Norway from 2009 show that between 40-60 % of all workers between 16-66 years report that their

musculoskeletal complaints totally or partially are due to their job situation (NOA, 2011). The World Health Organization defines musculoskeletal disorders as work-related when there is a causal relationship to the work environment and work tasks (WHO, 1985)

Musculoskeletal disorder is however not a well-defined concept even though it is frequently used. It can be regarded as an umbrella term that includes a variety of conditions which involves nerves, joints, muscles, tendons, ligaments and bones (Bernard, 1997). Both diagnosed diseases as degenerative diseases and inflammatory conditions as well as reported pain without clinical findings affecting the loco motor system are regarded as musculoskeletal disorders. The symptoms range from discomfort, minor aches, and complaints to more serious medical conditions requiring time off work, medical treatment and possibly permanent disability and loss of employment (Brage, 1998). Common for most musculoskeletal disorders are the experience of pain. Pain is a subjective experience and can be defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage” (Merskey, 1979). This widely used definition of pain used by the International Association for the Study of Pain (IASP), acknowledges the subjective nature of pain and that there can be substantial individual differences in pain experience regardless of equal stimuli. Muscle pain can originate from the striated muscles including the fascia, tendons and insertions and is often perceived as aching and cramping at the same time as it can be difficult to localize (Mense, 2003). In this dissertation the focus was on self-reported pain in the neck and shoulder region without emphasize on clinical findings. The pain reports in the three papers do therefore not distinguish between diagnosed diseases and pain without clinical findings.

Work-related neck and shoulder pain

In the working population one of the most frequently reported complaints are pain in the neck and shoulder region (NOA, 2011). It is however a minority of those reporting pain that have severe disability. The burden and determinants of neck pain in workers has been systematically reviewed as part of the Bone and Joint Decade (Côté et al., 2008). One hundred and nine papers were of scientifically acceptable quality and of those 34 had longitudinal

design (Côté et al., 2008). The review found that each year between 11 % and 14 % of workers were limited in their activities because of neck pain. They also argued that each year at least 5 % of the working population develops frequent or persistent neck disorders and that depending on their occupations up to 10 % will experience at least one episode of activity limitations because of neck pain (Côté et al., 2008). In another review the annual prevalence of neck pain in the general working populations was found to vary a great deal in each country, from 27 % in Norway to 48 % in Quebec, Canada, while the annual prevalence of shoulder pain in an occupational setting ranged from 5 % to 47 % (Luime et al., 2004). Neck and shoulder pain is however often considered as one entity not separating between pain in the neck and the shoulders (Marcus et al., 2002; Tornqvist et al., 2001). One reason for this may be that symptoms of pain from the two regions may overlap and that neck pain may signal a shoulder problem while a shoulder pain may signal a neck problem. Another reason may be that they share many of the same work-related risk factors. It has also been found a strong evidence for an association between the two pain regions in longitudinal studies (Mayer et al., 2012). The prevalence of the combined neck and shoulder pain has been found to vary between 22 % and 40 % (Andersen et al., 2007). The pain prevalence also varies across occupations and among workers in manual occupations. In Paper I and II of this dissertation, as in many other studies, neck and shoulder pain is not separated as the mechanical workload assessed in these two papers were regarded as possible risk factors for both neck pain and shoulder pain. However in Paper III the two are separated and shoulder pain was chosen as the outcome variable when assessing work with arms elevated as a possible risk factor.

When focusing on pain in one specific body region, like in this dissertation, it is important to be aware that regional musculoskeletal pain usually coexists with pain in other body regions. A cross-sectional study found single site pain as relatively rare, although musculoskeletal pain was frequently reported (Kamaleri et al., 2008). This finding is from the general population in Norway, but similar results have also been found among workers (Coggon et al., 2013). The study by Coggon and colleagues comprised of workers from 18 countries and showed that those reporting musculoskeletal pain at a specific site were twice as likely to report pain in another body region compared to the workers without pain (Coggon et al., 2013). It has also been shown that the number of pain sites is relatively stable across adulthood (Kamaleri et al., 2009). Even though musculoskeletal pain can coexist and the impact of the exposure on

specific body regions are difficult to differentiate, it may still be of importance to separate the different body regions when trying to identify possible risk factors. In this dissertation it was especially relevant to differentiate the body regions in pain as work-related risk factors like heavy lifting and work with arms elevated physiologically have more impact on neck and shoulder pain than pain in other body regions.

There has been a large amount of research aiming at identifying the risk factors of neck and shoulder pain among workers (Mayer et al., 2012). Individual factors, psychosocial factors neck and shoulder pain. The individual factors include gender, age, previous musculoskeletal pain, ethnicity, socioeconomic background, low physical capacity and smoking (Cagnie et al., 2007; Hamberg-van Reenen et al., 2006a). Psychosocial factors like high job demands, low social support at work, high job strain, high role conflict and poor job satisfaction can be of importance (Ariëns et al., 2001b; Christensen and Knardahl, 2010; Hannan et al., 2005; Kraatz et al., 2013). Awkward work postures, work with hands above shoulder level, sedentary work position, manual material handling, repetitive work, precision work and generally poor physical work environment are examples of mechanical factors that may be associated with neck and shoulder pain (Ariëns et al., 2000; Mayer et al., 2012).

Several authors have critically reviewed the evidence regarding both mechanical workload and psychosocial workplace factors and their association with neck and shoulder pain (Palmer and Smedley, 2007; van Rijn et al., 2010; Walker-Bone and Cooper, 2005). Some of the limitations that the reviews highlight are inconsistent associations and the diversity of methodology and analytic approaches (van der Windt et al., 2000; van Rijn et al., 2010). The earlier reviews have also mostly been based on cross-sectional studies meaning that the underlying causality of the associations cannot be verified. Fortunately there has been an increase in prospective studies and in 2013, a systematic review of the longitudinal studies concerning the association between psychosocial workplace factors and the development of neck and shoulder pain, was published (Kraatz et al., 2013). Eighteen longitudinal studies were included in the review and the results indicated an association between high levels of psychological job strain, job demands and low levels of social support at work and neck and shoulder pain (Kraatz et al., 2013). The studies were mostly based on the job demand control model by Karasek (Karasek, 1998). Similarly, in 2012 there was published a systematic review on the longitudinal association between mechanical workload and neck and shoulder complaints (Mayer et al., 2012). The review included a total of 21 studies (19 of them were

regarded as high quality studies). The results confirmed existing knowledge (Bernard, 1997) on the association between manual material handling (forceful exertion, static contraction and prolonged static loads) and neck and shoulder pain. In addition the longitudinal studies indicate a strong evidence for an association between shoulder pain and trunk flexion/rotation and working with hands above shoulder level (Mayer et al., 2012). Although there have been an increased number of studies with longitudinal design, a recommendation to conduct more prospective studies with objective assessments of the workload exposure was emphasized. This may be necessary to identify a possible dose-response relationship between mechanical workload and neck and shoulder pain. In an attempt meet these recommendations the mechanical workload was in this dissertation assessed both with objective and self-reported measurements.

The mechanisms leading to neck and shoulder pain are probably products of an interaction of several different work-related and individual risk factors. The whole picture is believed to be complex and remains to be solved. The main exposure variable in all three papers of this dissertation is mechanical workload measured in three different ways. Both individual and psychosocial variables are included in this dissertation acknowledging the possibility that the associations may be precluded with insufficient control of pain modifiers and the possible interactions between the various factors.

Mechanical workload

Being at work is believed to prevent disease and create good health, but it is also evident that some factors in the work environment contribute to disease and disability (Siegrist and Wahrendorf, 2009). For centuries the nature of work has influenced the health of workers. Already 300 years ago, the Italian physician Bernardino Ramazzini was the first to systematically outline the relationship between certain working conditions and specific health problems. He made a list of work-related disorders in over 50 professions. In "De Morbis Artificum Diatriba" [The Disease of Workers] from 1713 you can read the following: "... Unnatural body positions can affect the body's natural structures and thus gradually develop into serious illnesses ... in example weavers struggles with their arms, hand legs and back... while printers and tailors get paralysis of arms and legs..." (Ramazzini, 1964). Ramazzini classified diseases and injuries based on health risk from the individual's occupation. Using occupation as a proxy for the exposure of mechanical workload has limitations and disadvantages. Today's research is dependent on more accurate and precise measures of the exposure. Much research has been done in this area and there is little doubt that musculoskeletal pain may be affected by mechanical workload in terms of one-sided and repetitive muscle use (Mayer et al., 2012). Several systematic reviews have however pointed out the need of additional research with the use of objectively measured exposure (Côté et al., 2008; Wai et al., 2010). To achieve increased understanding of the effect of mechanical workload on the musculoskeletal system, the load has to be described by appropriate data. A high quality quantification of the mechanical exposure is therefore essential. The exposure is seldom simply present or absent. In quantifying mechanical workload it has been suggested by Winkel & Mathiassen to assess the following three dimensions: the level of exposure (magnitude, degree or amount), repetitiveness (frequency of shifts between force levels) and the duration (time period) (Winkel and Mathiassen, 1994). Various methods are available to assess mechanical workload and include the use of direct technical measurements, observational methods, and self-reported questionnaires (Takala et al., 2010; van der Beek and Frings-Dresen, 1998; Wells et al., 1997). They all have limitations and advantages and the selection of methods for assessing workload are usually based on several aspects like; the objective of the study, the resources available for the data collection and the type of work that

is being assessed. The most commonly used approach to evaluate mechanical workload are self-reports and observational methods. However, the most advantageous to ensure accurate, precise and valid exposure data is to use repeated (i.e. measure on several days) and prolonged (i.e. measure repeatedly during a full working day) technical measurements on each individual in a large study group (Hansson et al., 2010; Mathiassen et al., 2003; Spielholz et al., 2001). This is on the other hand often difficult to achieve. Since all the different exposure methods have limitations, it has been purposed that the use of both self-reports and direct measurements can enhance the capacity to capture the true mechanical workload (Stock et al., 2005). In light of these recommendations the exposure data in this dissertation was based on mechanical workload assessed using three different methods; self-reported mechanical workload (Paper I), indirect technical measurement of muscle activity during work (Paper II) and direct technical measurement of arm posture during work (Paper III).

Self-reported mechanical workload (Paper I)

Mechanical workload is a quantification of the physical requirements associated with performing a given task. Self-reported exposure data obtained by questionnaires may be the most appropriate when obtaining the exposure in large working populations. Self-reported mechanical workload has also economical advantages as they are less expensive and less time consuming than technical measures. Self-reports have nevertheless been claimed to lack validity due to the low levels of association with direct technical measurements (Spielholz et al., 2001). The self-reported mechanical workload is not linearly related to the direct technical measurement, indicating that they may in some extent capture different aspects of the mechanical workload. The self-reported mechanical workload measure is by some regarded as a psychophysical measure of exposure where the subjects response reflects a variety of stimuli simultaneously which cannot be measured directly (Barrero et al., 2009). Another reason might be that questionnaires often evaluate average or usual exposures while the technical assessment evaluates exposure continuously over a specific time period (Barrero et al., 2009). The validity of the exposure data is dependent on how the questions are worded and how the answers are scaled (Wiktorin et al., 1996; Wiktorin et al., 1993). The self-

reported exposure captures the individuals own perception of the mechanical workload, meaning that similar work tasks with similar objectively measured mechanical load can be perceived substantially different by each individual. These variations can lead to confounding results. There are a wide variety of questionnaires assessing mechanical workload. In 2005, a systematic review evaluated the reproducibility and validity of these questionnaires (Stock et al., 2005). Fifteen articles were included and only 2 of them evaluated both validity and reproducibility of the questionnaire. The overall result from the review was that the reproducibility was better for general body postures compared to postures involving a specific region (Stock et al., 2005). The rationale for using the self-reported mechanical workload measure in Paper I was that it obtained exposure data for the entire cohort and both the validity and reproducibility of the questions were evaluated (Balogh et al., 2001).

Trapezius muscle activity during work (Paper II)

The workload can be objectively measured either by a physiological approach (i.e. measuring blood pressure, heart rate or muscle force) or a biomechanical approach (i.e. measuring body postures and movements). The physiological approach is aiming to measure the energy cost of performing a task by e.g. muscle force (Åstrand et al., 2003). Muscle forces are difficult to measure directly. Indirectly however one can measure the electrical muscle activity using electromyography (EMG). The assumption that there is an association between the EMG measured muscle activity and muscle force is the basis for many applications of EMG. Surface EMG recordings of the upper trapezius have been used in occupational studies, and positive relationships between muscle activity and muscle force have been found (Aarås et al., 1992; Lippold, 1952). Upper trapezius muscle activity during work has also been found to be independent of postural and biomechanical demands. An increased cognitive load have been found to provoke increased muscle activity (Wærsted, 1997), and the muscle activity at work may therefore be regarded as a combined measure of both mechanical and cognitive aspects. Mixed results have been found in studies on the relationship between work-related muscle activity and neck and shoulder pain and the relation is therefore debated (Jensen et al., 1993; Lund et al., 1991; Takala and Viikari-Juntura, 1991; Vasseljen and Westgaard, 1996; Westgaard, 1999; Østensvik et al., 2009a). In Vasseljens dissertation from 1995 it was

highlighted that an increased muscle activity was related to work-related shoulder and neck myalgia among manual workers, but this was not found among office workers (Vasseljen, 1995). Indicating that the differences in association may be related to the populations studied. Differences in the quantification of muscular activity in earlier studies may also explain some of discrepancies in the results. The rationale for measuring upper trapezius muscle activity in this dissertation was that we analyzed the muscle activity in a different way than most previous studies. Commonly the exposure has been analyzed using a mean value of the muscle activity during a certain recording time. This method however disregards the duration of the activity. By including only those periods with sustained activity (defined in Paper II as an activity lasting >4 minutes) we could investigate the impact of duration or persistence of the exposure which has rarely been done in earlier studies.

Arm elevation during work (Paper III)

The quantification of the mechanical workload associated with performing a given task may also be evaluated by a biomechanical approach. This approach is aiming to measure the load on the musculoskeletal system, measuring postures and movements (Åstrand et al., 2003). Working posture like working with arms elevated is an important factor when determining the shoulder load. When the arms are elevated and unsupported the gravity creates a load which must be counteracted by the shoulder muscles. The shoulder load is highest at 90 degrees (Jensen, 1999). Using direct technical field measurements of working posture is by many assumed as a “gold standard” for the true exposure (Stock et al., 2005), and one often used method is inclinometers. Measuring postures with inclinometers show better validity, accuracy and precision compared to observational methods (Hansson et al., 2010; Spielholz et al., 2001), and is one of the reasons why this method was used in paper III of this dissertation.

A systematic review found that working with elevated arms is associated with the development of neck and shoulder disorders in longitudinal studies (Mayer et al., 2012). Only 10 of the 21 studies in the review had objective assessment of the mechanical workload. All these 10 studies used observational methods and none had direct technical measurements of exposure (Mayer et al., 2012). The rationale for measuring arm posture during work using

direct technical measurements in this dissertation was that there is a lack of longitudinal studies using this method when identifying risk factors for neck and shoulder pain. In the current dissertation a field measurement of arm position during a whole working day using bilateral inclinometers were used in Paper III.

How can mechanical workload influence neck and shoulder pain?

Exposures to mechanical workload are believed to generate acute responses that are short-lasting reversible physiological changes, in addition to more long-lasting effects. The effects over time may either be positive training effects or negative effects resulting in musculoskeletal pain, injury or disorder. The level, repetitiveness and duration of the mechanical work exposure are relevant when evaluating the possible effect on musculoskeletal health. The workers physical capacity (how the muscles “cope” with the mechanical workload) may also be a relevant factor in evaluating the effect of exposure. Most people are however unable to tolerate prolonged, intense, static muscular work (Åstrand et al., 2003). Work with elevated arms is an example of mechanical workload that may require static and prolonged muscle force activation in the shoulder muscles. When the arm is hanging straight down or in a supported position the effect of gravity is counteracted by ligament force, passive muscle forces and bone contact forces. When the arm is elevated and unsupported however, gravity creates a shoulder moment which must be counteracted by the shoulder muscles. Regarding arm posture there are three parts of the deltoid muscle, the upper trapezius muscle and infraspinatus muscle that show considerably higher activity when the arm is flexed or abducted compared to hanging straight down (Sigtholm et al., 1984). The magnitude of muscle blood flow increases with increasing muscle force. At the same time the blood flow decreases with increasing intramuscular tissue pressure. The intramuscular pressure therefore plays an important role since it impedes the blood supply and prolonged insufficient blood supply may cause malfunction on muscle tissue. The intramuscular pressure in the supraspinatus muscle increases when the arm is elevated from 0° to 30° and 60° but almost no pressure increase occurs from 60° to 90° (Järvholm et al., 1988a). The intramuscular pressure may exceed 50mmHg already at 30° arm abduction which also impedes blood flow (Jensen et al., 1995). Muscle fatigue is hypothesized to be accompanied

by pain when muscle activation levels are so high that they impair blood flow. Muscle contraction pressure during work, corresponding to 16% of maximal voluntary contraction, has been found to reduce local muscle blood flow significantly (Järvholm et al., 1988b). For example the high intramuscular pressures found in the supraspinatus muscle during work with the arms elevated has been found to impede local muscle blood flow (Järvholm et al., 1988b). It has therefore been suggested that recurrent work exposures to static loads over time may damage poorly vascularized areas of the muscles and tendons resulting in pain (Jensen et al., 1994; Järvholm et al., 1988b). Muscle force development implies a large number of cascading physiological responses which acutely or more prolonged over time may overload the tissue. The degree of physiological change/response depends on the type of muscle contraction, duration and pause frequency in work.

The current literature provides valuable information on possible risk factors for neck and shoulder pain, but the pathological basis of neck and shoulder pain is poorly understood. There are however multiple hypotheses and theories on the pathophysiological mechanisms involved in the development of musculoskeletal pain. As early as the in the 1940s it was hypothesized that pain was a consequence of a sustained spasm of skeletal muscles. *Travell's hyperactivity hypothesis* assumed that muscle pain was a consequence of an energy crisis caused by sustained muscle fiber activity. It implied that there was a positive feedback loop which led to a vicious circle between sustained muscle activity and muscle pain (Travell et al., 1942). In 1991 *the vicious circle hypothesis* was modified by Johansson and Sojka (Johansson and Sojka, 1991). This hypothesis suggested that there is a self-maintaining vicious circle where the muscle activity amplifies the muscle pain and vice versa and that the γ -muscle spindle system plays a central role. This hypothesis provides a possible explanation on the sustainment of muscle pain it does however not explain the initiation of muscle pain.

In contrast to the hyperactivity hypothesis, Lund et al (1991) concluded in a literature review that there was evidence that muscle pain does not cause muscles to become hyperactive and introduced: *The pain adaption model* (Lund et al., 1991). This hypothesis purposed that the muscle pain would cause a reduction in muscle activity as a protective reflex adaption to pain.

For work with high force requirements it is considered plausible that muscle activity may play a significant role in the development of muscle pain. However in work constituting low levels of force requirements the plausible association with muscle pain is not so obvious and highly

debated. *The Cinderella hypothesis* tried to explain how myalgia could occur even at very low levels of muscle contractions (Edwards, 1988; Westgaard and Bjørklund, 1987). It was based on the Henneman size principle which is a well-documented physiological principle that states that the contraction efforts are exerted by a small part of the muscle when power demands are low (Henneman et al., 1965). The Cinderella hypothesis suggested that when the same muscle fibers are persistently active through working with monotonous work, it gives rise to local metabolic changes and fatigue development and subsequent muscle pain (Edwards, 1988; Westgaard and Bjørklund, 1987). When the low threshold motor units are overloaded during sustained static work they never get any pauses to recover – thus the metaphor to Cinderella (Hägg, 1991). The result of active motor units that are working close to its maximal capacity over a sustained period of time it is hypothesized to lead to local hypoxia, elevated intracellular Ca^{2+} and finally muscle damage and pain (Gissel, 2000).

There are a large number of studies showing various physiological changes in muscle fibers during prolonged muscle activity. There is however few studies that have found associations between changes in muscle fibers and musculoskeletal pain. Based on the lack of findings between muscle-cell activation and pain, Knardahl (2002) introduced; *The blood vessel-nociceptor interaction hypothesis* (Knardahl, 2002). It purposed that the nociceptors are activated by factors regulating blood vessels or/and factors from the microcirculation. This is based on the knowledge that the skeletal muscle nociceptors are located in the wall of arterioles and in the connective tissue (Mense, 1993). The mechanisms to muscle pain is in this hypothesis linked to vasodilatation, the release of algogenic factors and inflammation and assuming that muscle cell activity is less important (Knardahl, 2002; Knardahl, 2005).

The pathophysiological mechanisms involved in the development of muscle pain may differ with the different muscle activity patterns (dynamic vs. static) and the muscle activity intensity (high vs. low muscle force). The mechanisms may also differ in different stages of muscle pain development. Even though the hypotheses presented here have different perspectives on the pathophysiological mechanisms it does not necessarily mean they are mutually exclusive but can coexist. This dissertation does not deal with the verification of any of these hypotheses as it does not have an experimental design. None of the three papers are based on a specific hypothesis of the pathophysiological mechanism behind the muscle pain. They are however all based on the hypothesis that mechanical workload requiring static and prolonged muscle force activation in the shoulder and neck muscles over time may result in

neck and shoulder pain. In Paper II and III the temporal aspect of the mechanical exposure is emphasized, with focus on the relative time with prolonged mechanical workload.

Young workers

When assessing mechanical workload and its association with neck and shoulder pain, selection bias may arise from differences in age, occupation, length of employment and working tasks etc. The subjects in the three papers of this dissertation was selected with this in mind, and consisted of young workers with similar age and minimal exposure to earlier mechanical workload. It is however important to acknowledge that young workers are a very heterogeneous group at different phases in their life. This dissertation consisted of technical school students entering working life and facing the transition period from “school to work” and “youth to adulthood”. This period can be considered as a highly vulnerable stage, as the young workers still can be in physical, cognitive and psychological development. They are however an important study population as they are less studied and particularly vulnerable in work environments due to their lack of work experience, skills, training and awareness of risks. They may also be unaware of their rights and employers’ duties regarding health and safety, and they may be reluctant to speak out about problems and keen to please their new employer.

It is widely acknowledged that young workers are at higher risk for work injuries and accidents compared to older workers (Laberge and Ledoux, 2011). Less focus has been on other work-related health problems among this group. Musculoskeletal disorders are most common among the middle-aged and older workers, however in recent years there has been more attention to the fact that young workers also experience these symptoms (Breslin et al., 2007; van Nieuwenhuyse et al., 2013; van Nieuwenhuyse et al., 2006; Work, 2007).



Photo: European Agency for Safety and Health at Work (EASHW)

Young workers represent the workforce of the future and internationally the attention on health and safety of young workers has increased. The European Agency for Safety and Health at Work (EASHW) launched a campaign called "Safe Start" in 2006 to highlight young people's risk factors at work, and what one can do to reduce them (EASHW, 2006). The same year The Institution of Occupational Safety and Health (IOSH) launched their "Putting young workers first" campaign, which focused on making health and safety a government priority in education. In Norway statistics show that already at an early age workers report work-related musculoskeletal pain. Fourteen percent of the male workers and 25% of the female workers aged 16-24 years reported work-related neck and shoulder pain (NOA, 2011). A recurrent pattern from the same statistics shows that the proportion of workers reporting mechanical exposures, is larger among younger (16-24 years) than among older professionals (NOA, 2011). These figures show the relevance to explore other health outcomes than only injuries and accidents among this group. It also highlights the need to explore the relationship between mechanical workload and neck and shoulder pain among young workers, which is the main aim of this dissertation.

The overall incidence and prevalence of musculoskeletal pain increases with age at the same time as older workers have on average a longer exposure to risk factors at work and therefore a greater probability of developing work-related diseases simply because of their longer working careers. It has been shown that many work-related health problems are cumulative in nature and it has been hypothesized that younger workers report less work-related

musculoskeletal pain because of the fact that occupational diseases often need a cumulative exposure and latency period to develop. The comparison of prevalence of work-related diseases by age does not necessarily correctly reflect the effect of work-related factors on the health of young workers. It could nevertheless be important to pay attention to the health risks in young workers, to reduce the possibility of developing a work-related health problem later in life. On the other hand several studies have questioned if musculoskeletal problems experienced in adulthood already is formed during adolescence. Studies have indicated that pain in childhood and adolescence tends to persist (Ståhl et al., 2008) (El-Metwally et al., 2004). It has also been hypothesized that the basis of pain in adulthood may be formed during an early age (Brattberg, 2004). Among Norwegian adolescents (aged 13-18), about half of the girls and one third of the boys reported chronic non-specific musculoskeletal pain (Hoftun et al., 2011). The neck and shoulder region was most commonly affected (Hoftun et al., 2011). Another Norwegian study found that 25% of girls and 17% of boys at the age of 15 reported neck or shoulder pain (Haugland, 2000). In a large Finnish study done on 18-year-olds, it was found that 45% of women and 19% of men experienced neck and shoulder pain at least weekly. In the same study, there was a sharp increase in the number of 12-18 year olds with back, neck and shoulder pain at follow-up in a 10 year period (Hakala et al., 2002). With this perspective one can wonder what is "brought into the workplace" and "what is work-related". Research on risk factors for neck and shoulder pain has usually been done on older workers who have worked for a long time. In this dissertation we follow the study subjects from technical school into working life to increase the possibility to detect risk factors in this transition period.

Young people who choose vocational orientation at school, enters working life at a young age. They start off with two years of apprenticeship and can become fulltime workers at the age of 18. Electricians and hairdressers are examples of occupations where the recruitment of young workers is high. It is also occupations that are said to have a low average working age, 35 and 36 years, respectively (personal communication from industry organizations, autumn 2007). Drop-out in the first years of working life can have many causes, but so far it is mostly unknown. A Finnish study that followed female hairdressers through fifteen years (1980-1995), showed that hairdressers had 1.7 times higher risk of quitting their job because of neck or shoulder pain compared with female office workers (Leino et al., 1999). Another follow-up study of 91 hairdressers done at the University of Bergen in 1998 showed that 40% of

hairdressers had left the job at follow-up four years later. About 1/3 of those who left the job reported musculoskeletal disorders as a cause (Hollund et al., 2001). In a hairdressing survey commissioned by the Norwegian Hairdresser Teacher Association, a sample of 249 hairdressers was asked if they thought they would be in the profession after five years. Of those who answered no, about 30% stated health complaints as a reason to quit. A total of 93% reported having experienced pain in the arms and shoulders and 36% experienced high levels of pain (Folkenborg and Jordfald, 2003). Studies on electricians are often related to work accidents. However one American study among electricians showed that nearly 40% reported neck pain and 30% had shoulder problems (Hunting et al., 1994). The complaints had one week's duration or more with a frequency of at least three times in the past year. Electricians in this study were young, with an average age of 26 years (Hunting et al., 1994). An aging population and increasing number receiving disability pensions will increase the need for young workers to sustain throughout their working careers. In light of this, the current dissertation focuses on young workers from manual occupations and identifying if mechanical workload is a possible risk factor for the development of neck and shoulder pain early in work life.

STUDY OBJECTIVES

This dissertation focuses on the neck and shoulder pain in a cohort of young workers during their transition from technical school to working life. The overall objective was to identify early risk factors for neck and shoulder pain among these young adults with special emphasis on mechanical workload. The mechanical workload was quantified in three different ways; Self-reported mechanical workload (Paper I), objectively measured sustained upper trapezius muscle activity during work (Paper II) and objectively measured prolonged work with arms elevated (Paper III).

The more specific objectives in the three papers were:

Paper I:

- To examine the course of neck and shoulder pain among student hairdressers, student electrician and media/design students in their transition from school and into work life using a follow-up period over a 6.5 years with frequent measures of neck and shoulder pain.
- Identifying work-related and individual risk factors for neck and shoulder pain early in working life, with special emphasis on self-reported mechanical workload.

Paper II:

- To test the hypothesis which postulates that sustained periods with low level muscle activity during work predicts neck and shoulder pain. Defining sustained trapezius muscle activity pattern as the relative time with activity exceeding 0.5% EMG_{max} continuously >4 minutes.

Paper III:

- To test the hypothesis which postulates that work with prolonged periods requiring elevated arms predicts shoulder pain. Defining prolonged arm elevation as the relative time with arms elevated >60° and >90° continuously >5 seconds.

METHODS

Study design

All three papers in this dissertation are based on data collected from a prospective cohort study that was initiated in the autumn of 2002. Students from selected vocational programs at 13 high schools in the Oslo area were invited to the project and twelve schools accepted participation. The participants were recruited at the start of their second year at technical school and were followed over a 6.5 year period (October 2002- February 2009), through their first year of school (2002-2003) and through their apprenticeship period (2003-2005) and into working life (2005-2009). In this period they responded to frequent questionnaires every 4th month in addition to the following assessments (Table 1):

- At baseline (2002, T0) a comprehensive questionnaire on individual factors, work-related mechanical and psychosocial factors and musculoskeletal pain was completed during school hours. An examination by three physiotherapists was conducted the same day at school measuring weight, height, grip strength and muscle endurance etc.
- In the follow-up period, approximately every 4th month a questionnaire was mailed to the participant's home address, ((T1-T20) giving a total of 20 follow-up questionnaires).
- Approximately halfway in the follow-up period, a technical field measurement was performed assessing the mechanical workload objectively on a subsample of 43 subjects. This was done at a time where most of the participants had entered working life (2006, T14). The technical measurements included quantifying the upper trapezius muscle activity (using electromyography) and arm postures (using inclinometers) during a full working day.

Except for the participants which withdraw from the project in the follow-up period, all participants were mailed the questionnaire every 4th months regardless the fact that some changed occupational status. The three papers utilizes different parts of the data and this is illustrated in Table 1.

Table 1. An overview of the study design, the time period, the data collected and the data used in the individual papers (Paper I, II and III).

Year	2002-03			2003-04			2004-05			2005-06		2006-07		2007-08		2008-09					
Transition	School			Apprenticeship ^a			Work/study ^{a,b}														
Questionnaire	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Examination	X																				
EMG ^a /INC ^b															X						
Paper I (N=420)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paper II (N=40)														Qp	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Paper III (N=41)											T-1				T0			T1			T2

* During T3-T9 most of the participants were doing their apprenticeship period. However, some of the media/design students were still in school.

** During T10-T20 most of the participants had entered working life, there were however some that continued or started with other studies.

^a Electromyography (EMG) measurement on the upper trapezius during a full working day.

^b Inclinator (INC) was used to measure arm posture during a full working day.

Subjects

A total of 496 subjects in their second year of technical school were invited to participate in the project. They consisted of student electricians, student hairdressers and art media design students. A total of 456 students participated in the baseline measurement (92% of the invited), however 420 subjects were included in the project (85% response rate). The reason for this was that the participants younger than 18 years had to return a parental consent (in addition to their own written consent) after the baseline measurement. Thirty six subjects did not return the parental consent and were therefore excluded. The 420 participants in the cohort consisted of 267 (64%) females and 153 (36%) males. The participants median age was 17 (range 16-28). Hundred and sixty seven were student hairdressers (2% men and 98% women), 117 were student electricians (96% men and 4% female) and 135 were media design students (73% women, 27% men). The majority of the participants had parents from Norway or western countries (N=348, 83%), only 72 participants (17%) had parents from non western countries. Sixty six participants (16%) reported that their family had low socioeconomic status while 354 (84%) reported their families socioeconomic status as moderate or high. This was based on a single question on how well of they thought their family was. Three hundred and six participants (73%) perceived their general health as good or very good at baseline and 219 of the participants (52%) reported using tobacco regularly at baseline. Three of the participants reported suffering from heart disease and one participant had rheumatoid arthritis, they were, however not excluded from the analyses.

All of the participants were starting their second year of vocational education. Vocational education or technical school can be defined as education that prepares the students for a specific trade, craft or profession. It is sometimes referred to as technical education as the trainee directly develops expertise in a particular group of techniques (Kuczera et al., 2008). In this dissertation the subjects were called technical school students. In Norway technical school typically involve two years in school followed by two years of apprenticeship in a company. The first year of school provides general education alongside introductory knowledge of the vocational area. During the second year, courses become more trade-specific. The apprenticeship period is regarded as work and the apprentice receive a wage negotiated in collective agreements (Kuczera et al., 2008). In our cohort both the student

hairdressers and the student electricians had this organization of their vocational education including an apprenticeship period of two years. However most of the media design students had no apprentice period and were in school for a total of three years with a special focus on crafts and practical activities. After the three years of school they started further studies or started working.

The populations in the three papers of this dissertation were somewhat different. Paper I consisted of the entire cohort (n=420) and data from all the 21 questionnaires were used in the analyses. In Paper II and III the technical measurement at T14 constituted the main exposure variable and both papers were based on a subsample of the cohort. The subsample in Paper II (n=40) consisted of 23 women (15 females was working as hairdressers, 3 females were in other occupations and 5 were students) and 17 men (14 males was working as electricians and 3 males had other occupations like working in retail). Nearly the same subsample was used in Paper III (n=41) and consisted of 23 women (15 females was working as hairdressers, 3 females were in other occupations and 5 were students) and 18 men (15 males was working as electricians and 3 males had other occupations like working in retail). Figure 2 illustrates the selection process in the three papers.

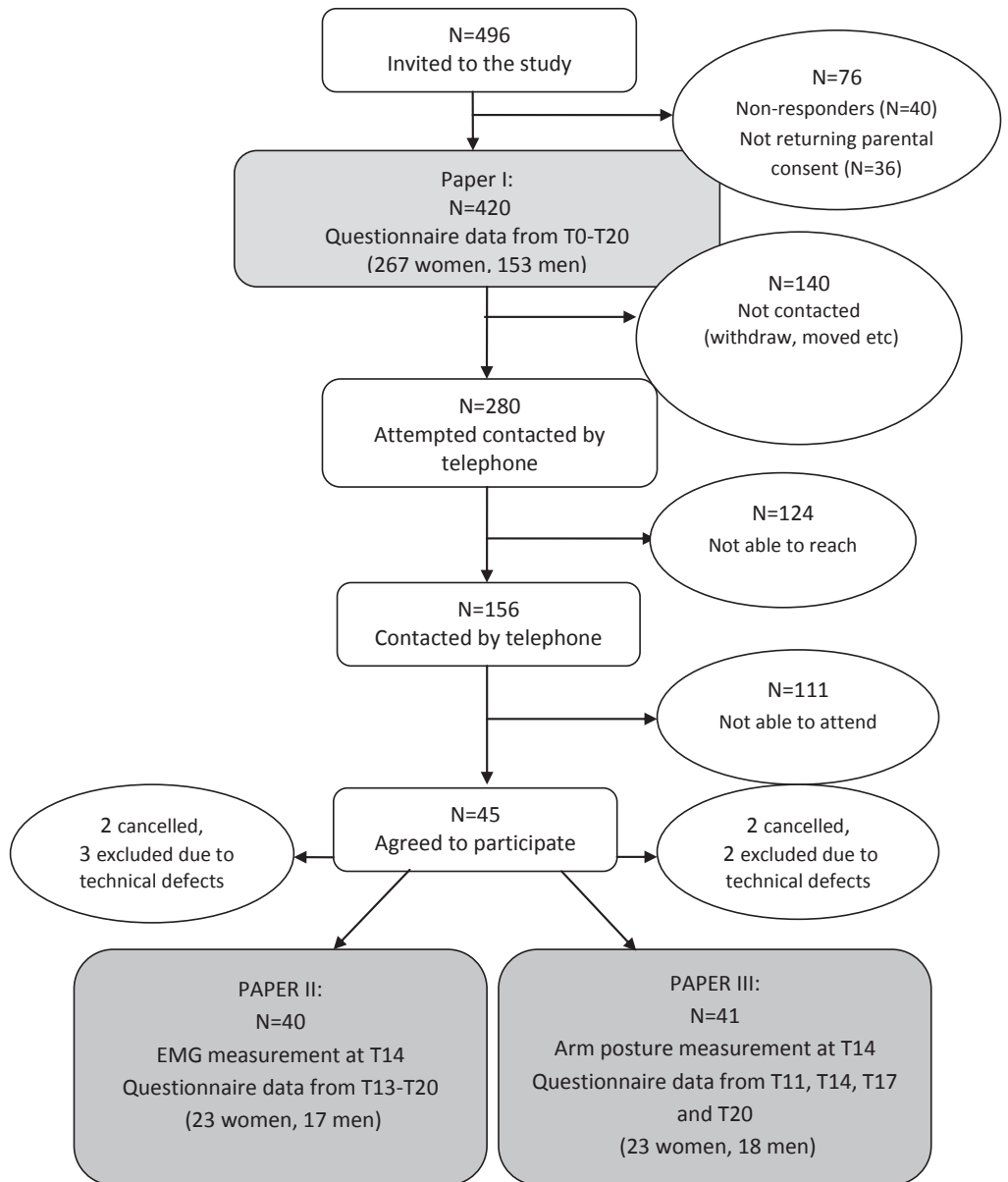


Figure 2. A flow chart of the selection process regarding populations in the tree papers and the number of subjects included.

Data collection

Questionnaire

The data collected by questionnaire at baseline, T0 (autumn 2002), contained questions on background and individual characteristics of each participant such as *age, gender, socioeconomic status, ethnicity*. These variables were all regarded as time-independent, and only assessed one time. The participants *perceived muscle tension* (used in Paper I) was also considered as a time independent variable and assessed once during the follow-up period (T8). The assumption that muscle tension was stable over time (time independent) was based on analyses on a subsample where the perceived muscle tension was assessed at three different time points and the score from the two following time points (T14 and T17) were significantly correlated with the score at T8 (Spearman's $\rho=0.67$, $p<0.01$ and $\rho=0.55$, $p<0.01$). Perceived muscle tension was evaluated by 11 questions on muscle tension habits (Theorell et al., 1991). The questions concerned whether the subjects had the habit of raising their shoulders, contracting their neck muscles, holding tools unnecessarily tensely, contracting their stomach muscles, wrinkling the forehead, contracting the eyelids, contracting the chewing muscles, holding their breath tensely, sitting on the front part of the chair and grinding their teeth. Each question had 3 response alternatives ranging from 0 (never) to 2 (often) giving a muscle tension index ranging from 0-22 (Nordander et al., 1999). The score was also converted into three; low (0-4), medium (5-10) and high (11-22).

Other variables as *neck and shoulder pain, mechanical workload, technical school affiliation, tobacco use and physical activity in leisure time* were collected at baseline, they were however regarded as time-dependent variables and therefore also collected at the follow-up questionnaires in the study period.

Neck and shoulder pain (Paper I and III): The participant's neck and shoulder pain for the preceding 4 weeks was reported at all 21 time points (T0-T20). To give a common understanding of pain region a mannequin drawing was used. The questionnaire assessed pain intensity (no pain (0), mild pain (1), moderate pain (2) and severe pain (3)) and pain duration (1-5 days (1), 6-10 days (2), 11-14 days (3) and 15-28 days (4)) (Steingrimsdóttir et al.,

2004). A pain index was calculated by multiplying pain intensity (0-3) and duration (1-4), giving a pain index ranging from 0 to 12. The reliability of this method has been found acceptable (Steingrimsdóttir, 2005).

Shoulder pain (Paper II): The shoulder pain was reported somewhat differently than the neck and shoulder pain in Paper I and III. The shoulder pain was reported by using a pain drawing where the participants were asked to shade in areas within an outline of a human figure that correspond to areas of their bodies in pain during the preceding 4 weeks (Margolis et al., 1988). This variable was assessed every year, at 4 time points (T11, T14, T17 and T20) were used in Paper III. The test-retest reliability of the pain drawing has been found reliable over time in both location and extent of pain (Margolis et al., 1988). In our study the number of squares that was shaded within a grid covering the shoulder region indicated shoulder pain. The sum of shaded squares in the left (0-9) and right (0-9) shoulder gave an index ranging from 0-18.

Self-reported mechanical workload (Paper I, II and III): Twelve questions were used to assess the mechanical exposure at work (Balogh et al., 2001). The participants were asked whether their work involved or required repetitive movements (1 question), precision movements (1 question), manual material handling (2 questions), vibration (1 question) and body postures (7 questions) such as working with their arms elevated or their back twisted or bent forward. The three response alternatives were; 0 (nothing/hardly nothing), 1 (somewhat) and 2 (a great deal). On the basis of the 12 questions an index was calculated ranging from 0-24 (Balogh et al., 2001). The index was converted into three categories; low (0-6), medium (7-11) and high (12-24). This was done on the basis of distribution of the data. In Paper I both the index and the categorized variable were used. The mechanical workload was assessed at baseline and 9 times in the follow-up period (Table 1).

Psychosocial work factors (Paper I, II and III): The participant's psychosocial working conditions were assessed using items selected from the General Nordic Questionnaire for Psychological and Social Factors at Work (QPS_{Nordic}) (Dallner et al., 2000). Quantitative demands and control over work intensity were each assessed by 2 questions. The questions on quantitative work demand were "Is your workload irregular so that the work piles up?" and "Do you have too much to do?". The questions assessing control over work intensity were "Can you set your own work pace?" and "Can you determine the length of your own

breaks?”. All the questions had 5 response alternatives ranging from 0 (never/seldom) to 4 (often/very often). The mean of the 2 questions made the score for each of the psychosocial working conditions. In Paper I the mean score was further converted into three categories; low (0-1), medium (1.1-2) and high (2.1-4), as done in an earlier study (Sterud et al., 2014). The participants psychosocial working conditions were monitored 5 times in the follow-up period (Table 1), but were not assessed at baseline.

Physical activity level in leisure time (Paper I, II and III): The level of physical activity in leisure time was measured by one question. The participants were asked how often they performed activities that led to increased heart rate and shortness of breath. The question had seven response categories ranging from 0 (never) to 6 (everyday) (Wold et al., 2000). In Paper I the score was dichotomized into two categories; ”once a week or less” (0-3) and ”twice a week or more” (4-6) as done in an earlier study of a subsample of this cohort (Wærsted et al., 2012). The participants physical activity level in leisure time were monitored at baseline and 9 times in the follow-up period (see Table 1)

Tobacco use (Paper I, II and III): The participants were also asked about their smoking and snuff habits. If they either were smokers or used snuff daily or occasionally they were characterized as tobacco users. Tobacco use was assessed at baseline and monitored five times in the follow-up period (Table 1).



Questionnaire assessment before the technical measurement (T14, autumn 2006)

Photo: Therese N Hanvold

Clinical examination

In conjunction with the baseline questionnaire (fall of 2002, T0) which was carried out during school hours, a clinical examination was also carried out on each participant by three physiotherapists. The examination included measuring *hand grip and shoulder muscle endurance*. Both hand grip and shoulder muscle endurance was assessed in an attempt to quantify the individuals physical capacity.

Hand grip strength (Paper I): Hand grip strength was tested at baseline and treated as time independent. The test was performed in standing position with the arms along the body and the hands pointing downward. Each participant performed three maximal contractions with their dominant hand using a hand dynamometer, model 78010 from Lafayette Instrument® (Lafayette, IN 47903 USA). The highest of three attempts was recorded (Reitan, 1985). On the basis of data distribution the score was also dichotomized into categories; low (0-29.5kg) and high (30-64kg).

Shoulder muscle endurance capacity (Paper I): The shoulder muscle endurance was tested at baseline and treated as time independent. The isometric endurance capacity in the shoulder muscles was quantified by the time (seconds) the participants could keep both shoulders abducted at 45 degrees with a load of 2 kg on each wrist. They were asked to hold the position as long as possible. This was done in concordance with protocol from a previous study (Brox et al., 1996). An upper limit was set at 900 seconds (15minutes). Four participants reached this limit. On the basis of the data distribution, the score was further converted into three categories; low (0-155), medium (156-245) and high (246-900).

Technical measurements

In addition to the questionnaire and clinical examination as described above, a technical field measurement was conducted in 2006/2007, T14. It consisted of a measurement of the mechanical workload during a full working day. Sustained muscle activity was measured using an EMG apparatus and arm posture during work was measured by means of inclinometers of the upper arms. A total of 43 subjects from the cohort participated.

Trapezius muscle activity during work (Paper II)

Upper trapezius muscle activity was evaluated by bilateral surface electromyography (EMG), recorded by 6 mm diameter, bipolar electrodes (E-10-VS, Medicotest A/S, Ølstykke, Denmark). The electrodes were placed with a 20 mm inter-electrode distance parallel to the underlying muscle fibers in standardized positions (Mathiassen et al., 1995; Veiersted, 1991). The root mean square (RMS) value was calculated for epochs of one-eighth of a second, and the recorded noise level was subtracted. The signal was then processed through a rectangular moving average filter of 1.625s length, giving an RMS window length of approximately 1.6s. The data was controlled for movement artifacts and electromagnetic interference as described by Hansson and co-workers (Hansson et al., 1997). This controlling procedure did not identify any artifacts or interference and therefore no parts of the recordings were excluded.

The full working day EMG recording was normalized in percent of the EMG_{max} of standardized maximum muscle contractions by having the arm abducted 90° in the scapular plane against a manual resistance applied by the investigator (Hansson et al., 1997). The mean EMG recording length was 6 hours and 22 minutes (range 3 h. 39 min - 8 h. 37 min). Sustained trapezius muscle activity was defined as the relative time (% of time during the full working day) with activity exceeding 0.5% EMG_{max} continuously for more than 4 minutes (Illustrated in Figure 3.). This duration was chosen on the basis of a recent methodological study on effects of EMG data processing procedures where it was found that 4 minutes was one of the preferable measures (Veiersted et al., 2013). An earlier study using similar episodes with sustained muscle activity (Østensvik et al., 2009b) and the distribution of our data was also important when choosing the exposure measure. In order to check how appropriate the choice of a 4 minute duration threshold was, control analysis was also done with duration thresholds of > 2 , > 6 , > 8 , > 10 and > 15 minutes, as well as with no demand on duration (i.e. including all 1.6 second RMS windows above 0.5% EMG_{max}). Widely used EMG measures like static muscle activity (10th percentile of the amplitude distribution) (Jonsson, 1982) and muscle rest (proportion of total time with EMG activity below 0.5% of EMG_{max}) (Veiersted et al., 1993) were also analyzed. For these measures we used RMS window length of one-eighth of a second which is in line with earlier studies (Cram et al., 1998). The EMG recording was done bilaterally and the relative time of sustained muscle activity was calculated for each side before a mean from the right and left EMG recording was used in the analyses. The relative

time of sustained muscle activity during a full working day was divided into three approximately equally sized groups (low (0-29%), moderate (30-49%) and high (50-100%)).

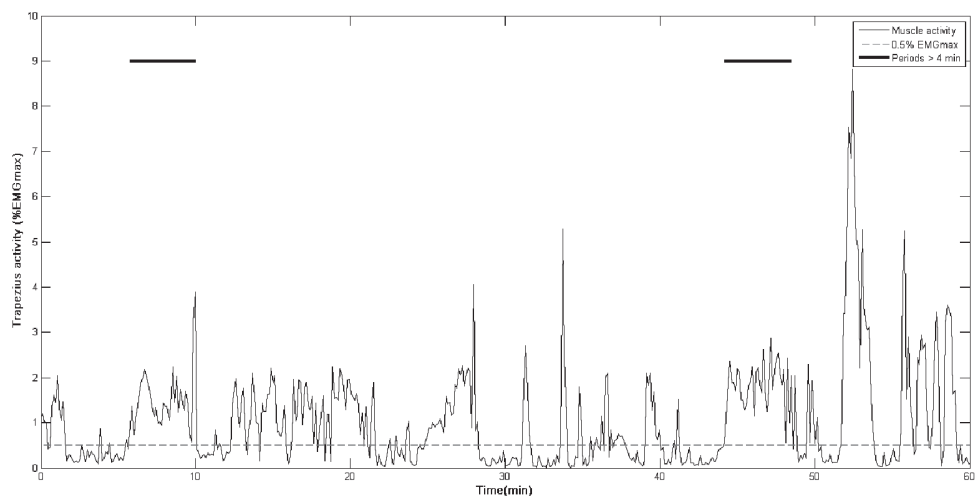
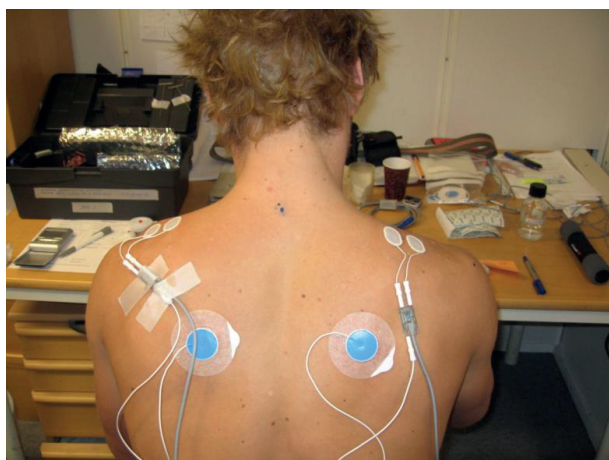


Figure 3. A 60 minute long segment of the surface electromyography recording of the upper trapezius muscle activity is shown. This figure illustrates periods of sustained upper trapezius muscle activity above 0.5% of EMG_{max} and lasting >4 minutes. In this 60 minutes segment there were two periods lasting >4 minutes (1st period = 4.02 minutes, 2nd period = 4.32 minutes, total = 8.34 minutes. The relative time of sustained muscle activity during these 60 minutes was therefore calculated to 14 %.)



Upper trapezius muscle activity assessed by bilateral surface electromyography.

Photo: Therese N Hanvold

Arm elevation during work (Paper III)

Shoulder postures and movements were assessed by an inclinometer on each upper arm. The inclinometers were fixed with double-sided adhesive tape below the deltoid muscle insertion. Data were sampled at 20 Hz and stored on a portable data logger fastened in a waist belt of the worker (Logger Teknologi HB, Åkarp, Sweden (Hansson et al., 2003)). The inclinometers measured the orientation relative to the vertical plane. The reference position = 0° elevation (normalization procedure) of the upper arm was done with the subject seated, with the side of the body leaning towards the armrest of the chair, and the arm hanging perpendicular while holding a 1 kg weight in the hand. The weight was used to stabilize the vertical position. Recording equipment was mounted in the morning before the start of the working day and a questionnaire was completed before the normalization procedures were initiated. The participants were instructed by the investigator to perform their ordinary work during the measurement day. The percentage of time spent with the upper arms elevated >30°, >60° and >90°, were used as measures to describe working postures (Moriguchi et al., 2013; Svendsen et al., 2004a). To give the time proportions of prolonged arm elevation, episodes lasting for >5, >10 and >20 seconds were processed. The lengths of episodes were chosen on the basis of earlier findings (Svendsen et al., 2004a). The percentage of time with arm elevation was calculated bilaterally before a mean from the right and left upper arm was used in the analyses. The mean duration of the measurements was 6 hours and 5 minutes (range 3 h. 39 min – 8 h. 37 min). Prolonged arm elevation was in the analysis defined as the relative time (% of time during the full working day) with arm elevation >60° continuously for more than 5 seconds with duration >5 seconds (Illustrated in Figure 4.).

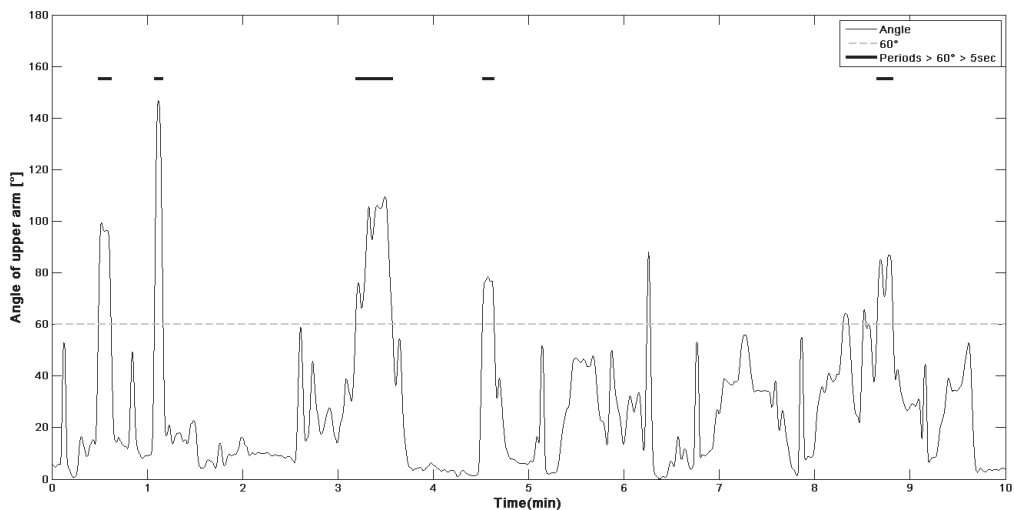


Figure 4. A 10 minute long segment of arm posture recorded by inclinometer is shown. This figure illustrates periods of arm elevation $>60^\circ$ with duration >5 seconds. In this 10 minute segment there were 5 periods lasting >5 seconds (1st period =8 sec, 2nd period=6sec, 3rd period=25sec, 4th period=8sec, 5th period=10sec, total=57seconds. The relative time of arm elevation $>60^\circ$ lasting >5 seconds in this 10 minute segment was calculated to 10 %).



Upper arm elevation assessed by inclinometer.

Photo: Gert-Åke Hansson & Therese N Hanvold

Missing data

Longitudinal studies have many methodological advantages at the same time as missing data is a frequent problem. The longitudinal study cohort in the current dissertation is no exception. During the 6.5 year project period, the missing data for the questionnaires ranged from 0% (missing n=0) at T0 to 73% (missing n=307) at T18. A total of 21 participants (5%) answered all the 21 questionnaires and a total of 183 participants (44%) answered >50% of the questionnaires. Thirty participants (7%) only participated at baseline, and were missing in all follow-up questionnaires. After 6.5 year period a total of 193 participants (45%) answered the last questionnaire at T20. In an attempt to decrease the amount of missing data several different strategies were used in this project. If a participant did not respond to a questionnaire, we sent out a reminder after 3 weeks. Reminders are the most common method for improving response rates, other incentives such as the use of monetary incentives have been used although the effect on response rate varies (Aadahl and Jorgensen, 2003; Olsen et al., 2012; Tjerbo et al., 2005). In our project we used a variety of minor incentives in addition to the reminder trying to reduce intermittent missing data and dropout. The incentive used included scratch lottery tickets for those who returned the questionnaire and conducting a lottery on questionnaire responses with the opportunity to win different items like MP3 players, photo cameras. Apart from not responding to the received questionnaire other reasons for missing data was also seen. At various points during the study's follow-up period there were participants that could not be tracked down, and after several unsuccessful attempts to find their new addresses these participants did not receive more follow-up questionnaires. Three participants died during the project period from 2002-2009, and 41 participants actively chose to withdraw from the study (n=4 (2003), n=19 (2004), n=5 (2005), n=3 (2006), n=2 (2007), n=6 (2008), n=2 (2009)).

In the evaluation of missing data there are usually distinctions between different types of missing. When participants do not fill in a single item or an item that is part of a multi-item instrument (item non-responders), it is known as *item missing*. When an eligible participant does not fill out or return the questionnaire as a whole (unit non-responders) it is known as *missing case*. Both of these missing data types are present in the data collected in this dissertation. It has been stated that the presence of missing data can make standard analyses

inappropriate as they give loss of efficiency and in some cases also introduces bias (Laird, 1988; Nakai and Ke, 2011). It is therefore important to know the amount and pattern of missing data. Longitudinal studies may vary in the length of follow-up period and number of follow-ups, in addition to if participants are “allowed” to return after missing measurements or not (Laird, 1988). This gives rise to different patterns of missing and within the longitudinal framework the missing data can be distinguished in two different patterns (monotone and non-monotone missing). *Monotone missing* is characterized by the data being available for all the assessments until the participants drop out permanently (Little and Rubin, 2002), and most literature on missing data focuses on monotone pattern of missing (Lin et al., 2004). It is however not uncommon in studies with several follow-up measurements that participants are absent from one or more measurements and subsequently reappear (Schafer and Graham, 2002). This is known as non-monotone missing data and is divided in; *Intermittent missing and Mixed missing*. The pattern is intermittent if there is a missing observation in between the observed, and a mixed pattern occurs if an intermittent missingness is followed by monotone missingness (Fielding et al., 2009). When a dataset consists of participants with different patterns of missingness, the analysis becomes more complicated (Xie, 2012). In the current dissertation the participants were throughout the whole follow-up period allowed to skip one or more follow-ups without being excluded from further participation. In our cohort we found both mixed and intermittent pattern of missingness among participants (Svenssen, 2011).

Furthermore, the data set in all the three papers presented in this dissertation consists of both time-dependent and time-independent variables. In all three papers the outcome variable was regarded as time-dependent and measured at several time points. In Paper II and III the mechanical exposure variable was regarded as time-independent, while in Paper I the mechanical exposure variable was regarded as time-dependent. Some of the variables in Paper I and II were regarded as time-dependent, yet they were not assessed at all time points (mechanical workload, psychosocial working conditions, tobacco use, and physical activity). This lead to missing data for all subjects at some of the time points because they were not assessed. This is known as missing by design.

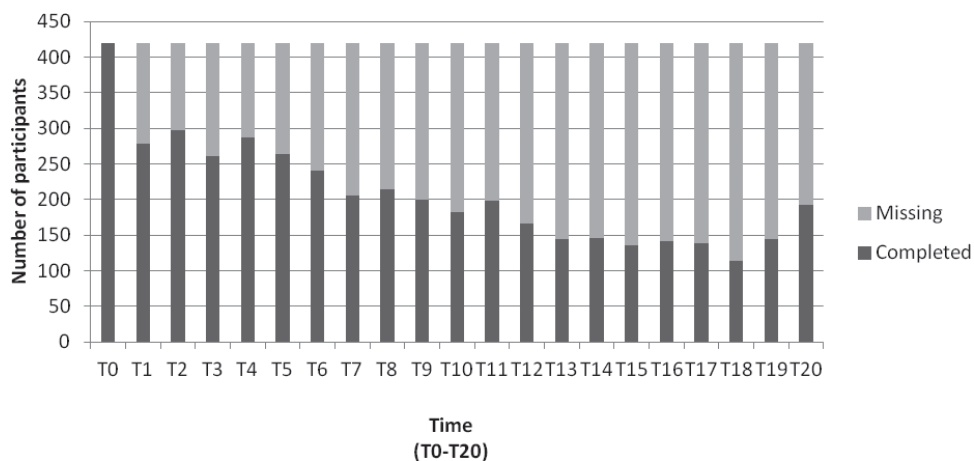


Figure 5. Missing data in Paper I, (N=420)

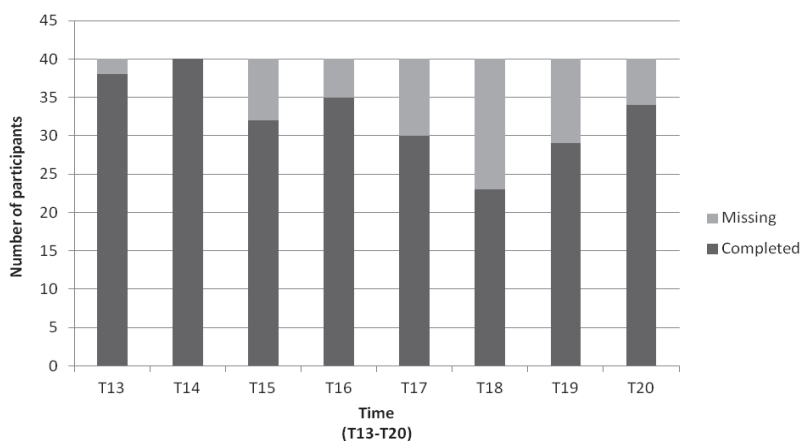


Figure 6. Missing data in Paper II, (N=40)

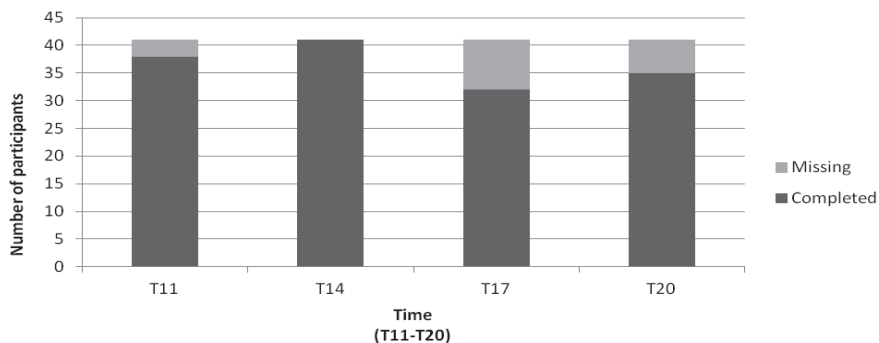


Figure 7. Missing data in Paper III, (N=41)

Generally missing data in longitudinal studies accumulates over time, resulting in an increasing amount of missing data for each monitoring point (Zunzunegui et al., 2001). The time between measurements can either be too frequent, so that the subjects get exhausted, or too seldom, so that the subjects lose their motivation (Bildt et al., 2001). In Paper I we had 21 monitoring points and saw a tendency of increasing number of missing cases for each time point, except for the last two questionnaires where there was a slight increase (see Figure 5). In Paper I and II there was less missing data, accompanied by fewer measurement points used and a lower number of participants (see Figure 6 and 7).

Data processing and statistical analyses

Imputation

An increasing number of longitudinal studies have also resulted in a higher amount of studies meeting challenges concerning missing data. There has therefore been a growing interest in the different ways of handling this problem and a huge amount of literature on how to deal with missing data is now available. Complete case analyses and single imputation techniques are the most commonly used methods to deal with missing (Eekhout et al., 2012; Wood et al., 2004). Multiple imputation is however currently considered as the best approach as they give more valid estimates (Enders, 2001; Graham, 2009; Schafer and Graham, 2002). Analyses using multiple imputations to handle missing data are nevertheless only valid when the missing are missing at random (MAR) or missing completely at random (MCAR). The data is missing at random if their absence depends on the observed data but not the unobserved data. Missing completely at random is when the missing data is not related or dependent on the observed and unobserved data. Both of these mechanisms of missingness are in contrast to when the data is missing not at random (MNAR). When the missing data is dependent on the unobserved data, in example if the cause of missing is due to the outcome itself, there is missingness not at random. When choosing the proper imputation strategy in our three papers we needed to understand the reasons why data were missing and if it was randomly or systematically missing. It was therefore done attrition analysis of the cohort (Svenssen, 2011). This analysis indicated no relevant selective missing. On the basis of the assumption that we

have missing at random, multiple imputation was chosen as the method for handling the missing data in the three papers. Multiple imputation is an approach rooted in the Bayesian statistics. It uses regression to predict the missing data on the basis of the complete data (Spratt et al., 2010). There are several steps in the multiple imputation procedure. Firstly the variables which were believed to correlate with the missing observations were selected. An imputation model was then made including all the variables included in the multivariate analyses. An a priori inclusion of outcome, exposure and confounders were therefore done. Secondly, the linear mixed model was carried out in order to produce multiple complete datasets with all the missing values filled in. A total of five imputed datasets were made. Finally, the multiple newly generated datasets were analyzed and all the estimates that were created for each dataset was combined into one set of estimates that were reported (Rubin, 1996). This was done in the same way in all three papers, however with different imputation models for each paper.

Statistical analyses

Statistical analyses were performed using The Statistical Package for Social Sciences (SPSS, version 18.0) and STATA (version 11.0 and 12.0). Evaluating group and gender differences chi-square statistics and the independent-samples Mann–Whitney U test was used. Spearman's rank correlation analysis ($\rho=\text{rho}$) and linear regression analysis ($\beta=\text{regression coefficient beta}$) was performed when evaluating the relationship between the outcome and exposure without considering the time-dependence of the variables. A significance level of 5% was adopted. When evaluating the longitudinal relationships, we chose to take into account the time-dependence of the variables and Generalized Estimating Equations (GEE-analysis) was used. This analyzing technique takes into account the dependency of the observations by adding a so-called “within-subject correlation structure”. The three papers in this dissertation the outcome variable is repeatedly measured over time (21 times in Paper I, 7 times in Paper II and 3 times in Paper III). When evaluating the longitudinal relationship between the outcome and exposure the GEE analysis takes into consideration that the observations (i.e. pain reports) are clustered within the participants meaning that there is a two-level longitudinal structure of the data (where the subject are the higher level and the

observations are the lower level as illustrated in Figure 8). This analysis includes adjustments for the correlation between the repeated observations within a subject. This is done by modeling the variability among the subjects (Twisk, 2006).

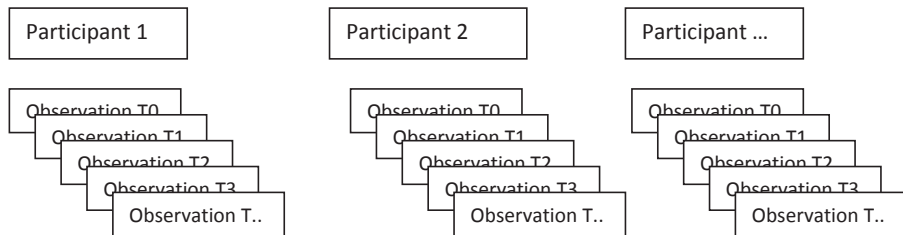


Figure 8. Illustrating the two-level structure and clustering in the data in all three papers in this dissertation.

In all three papers the discrete outcome variables showed overdispersion. This is characterized by a higher observed variance than the predicted variance. Overdispersion is a very common feature in applied data analysis because in practice, populations are frequently more heterogeneous contrary to the assumptions implicit within widely used simple parametric models. Due to overdispersion a negative binomial GEE-analysis was used in all three papers. For the effect estimates, rate ratio (RR), with corresponding 95% confidence intervals were reported in all papers (this is wrongly stated as IRR in Paper II, it is however correctly presented and interpreted as RR). In all negative binomial GEE-analysis an exchangeable correlations structure was used. The multivariate analyses were adjusted for covariates selected for inclusion a priori. In all three papers there was a gender difference in outcome and analyses were done both for the whole group and stratified by gender.

RESULTS IN SUMMARY

Paper I

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Twisk J, Veiersted KB.

A longitudinal study on risk factors for neck and shoulder pain among young adults in the transition from technical school to working life

Scand J Work Environ Health. 2014 May 23. [E-pub] Online-first article.

The study was undertaken to examine the course of neck and shoulder pain among a cohort of technical school students entering working life and identifying work-related and individual risk factors for neck and shoulder pain early in working life, with special emphasis on mechanical workload.

The main results showed that there was a significant increase of neck and shoulder pain. Even though relatively low pain severity levels were reported an increasing tendency towards moderate/severe pain levels among the participants was seen over the 6.5 year period (Figure 9a, 9b). A weak but positive association between self-reported mechanical workload and neck and shoulder pain was found, however, only significant among women. Clinically tested shoulder muscle endurance was negatively associated with neck and shoulder pain among men. Perceived muscle tension and ethnicity were the most consistent risk factors for neck and shoulder pain, found for both women and men.

The main conclusion of the study was that neck and shoulder pain increases over time in the transition from school to working life. Both work-related and individual factors were associated with the pain development and even though the effects are relatively small, they may still be of importance when considering the populations young age and the short exposure time to work-related factors.

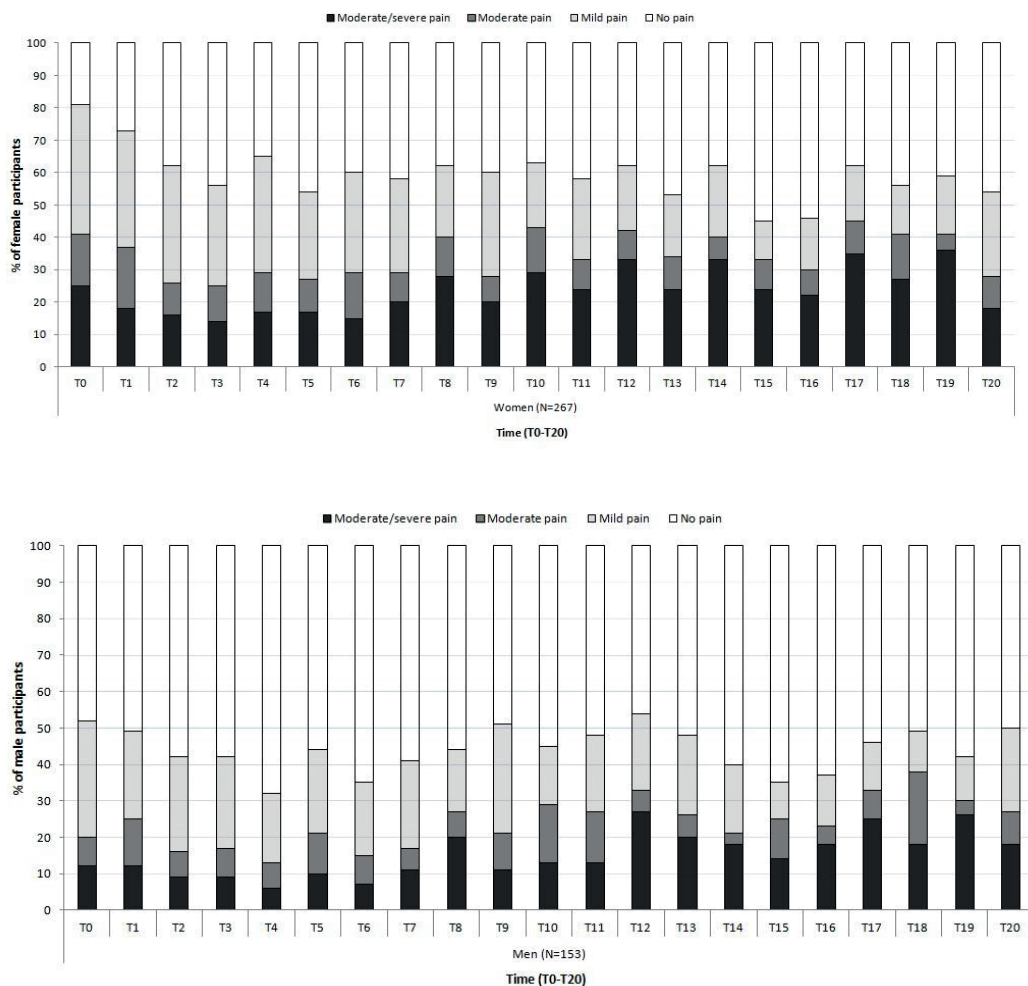


Figure. 9a. 9b. Neck and shoulder pain prevalence among female (9a) and male (9b) technical school students (T0-T2), in apprenticeship (T3-T9) and entering working life (T10-T20). Neck and shoulder pain (0-12) are categorized in four levels: No pain (index=0), Mild pain (index=1), Moderate pain (index=2-3) and Moderate/severe pain (index= ≥ 4). The prevalence (%) of each pain level is reported at each time point (T0-T20).

Paper II

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Stigum H, Twisk J, Veiersted KB.

The effect of work-related sustained trapezius muscle activity on the development of neck and shoulder pain among young adults.

Scand J Work Environ Health. 2013;39(4):390-400.

The hypothesis of the study postulated that sustained trapezius muscle activity pattern at work predicts neck and shoulder pain the following 2½ years.

Significant differences in sustained upper trapezius muscle activity between the occupational groups were found. Hairdressers worked with sustained muscle activity for 52% of their working day. Thirty three percent of the electricians did the same, while this amounted to 27% and 10% for those with various jobs and students, respectively

Sustained upper trapezius muscle activity pattern defined as the relative time with activity exceeding 0.5% EMG_{max} continuously >4 minutes, was associated with neck and shoulder pain the following 2½ years. Participants with a high levels of sustained muscle activity (50-100%) during their working day had a three time higher rate of neck and shoulder pain during a 2½-year period compared to participants with low sustained muscle activity (<30%) (Figure 10). When stratified by gender, the groups became small making it difficult to conclude. Analyses showed however a statistically significant association among men. This was not found among women even though a tendency of association was seen. The association between sustained muscle activity and neck and shoulder pain were strongest at the same time and shortly after the EMG measurement in both genders.

Analyses with minimum duration of sustained muscle activity of >2, 6, 8 and 10 minutes also showed an association with neck and shoulder pain. However choosing a minimum duration of 15 minutes or including all periods >0.5% EMG_{max} regardless of length showed no significant associations with pain.

Individual neck and shoulder pain reports Q1-7 related to sustained muscle activity (N=40)

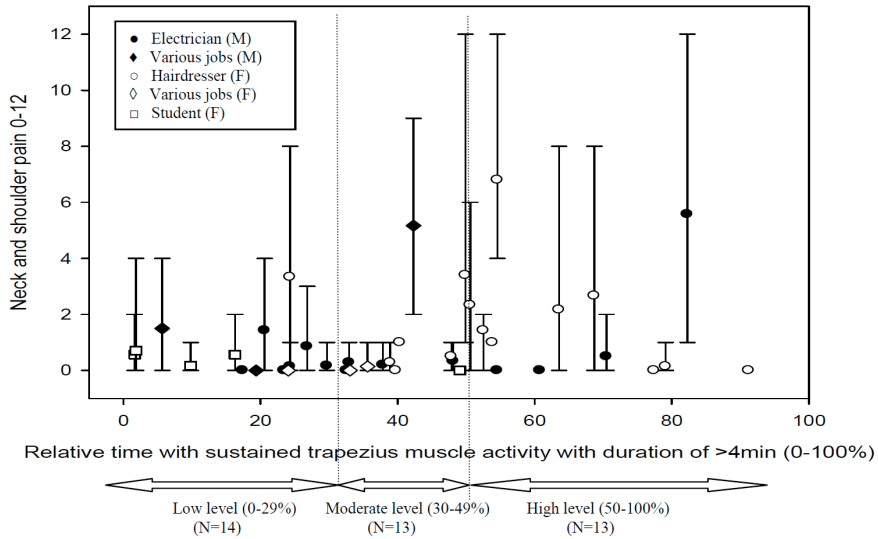


Figure 10. Individual reports of neck and shoulder pain over a 2 ½ year period (Q1-7) indicating median, min and max values. The sustained trapezius muscle activity is measured at Q1. Gender and occupational groups are also illustrated.

Paper III

Hanvold TN, Wærsted M, Mengshoel AM, Bjertness E, Veiersted KB.

Arm elevation during work and shoulder pain: a longitudinal study among young adults

Applied Ergonomics. 2015;47: 43-51. Online-first article.

The aim of the study was to examine the relative time with prolonged arm elevation $>60^\circ$ and $>90^\circ$ and its associations with shoulder pain during a 2.5 year period among young adults in their first years of working life.

Low levels of shoulder pain were found among the young adults in their first years of working life, especially among men, however a moderate increase was observed during the 2.5-year period. Among the participants a significant association was found between work-related arm elevation $>60^\circ$ and shoulder pain.

Among the female participants a significant association was found between shoulder pain and increasing arm elevation angles and increasing duration of episodes with arms elevated during work (Figure 11). The results showed no significant association between exposure to objectively measured arm elevation at work and shoulder pain among men (Figure 12).

The current study strengthens the evidence of an association between work with elevated arms and shoulder pain, especially among women. The association among women is however based on relatively few new cases of shoulder pain. It is nevertheless worth noticing that an association was found between repeated measures of shoulder pain and prolonged arm elevation, early in their working life. This indicates that work with prolonged arm elevation $>60^\circ$ and $>90^\circ$ may be harmful. The identification of early work-related risk factors may improve intervention strategies among this group of young adults. The low levels of shoulder pain in the male participants made it impossible to draw any conclusion of the association among men.

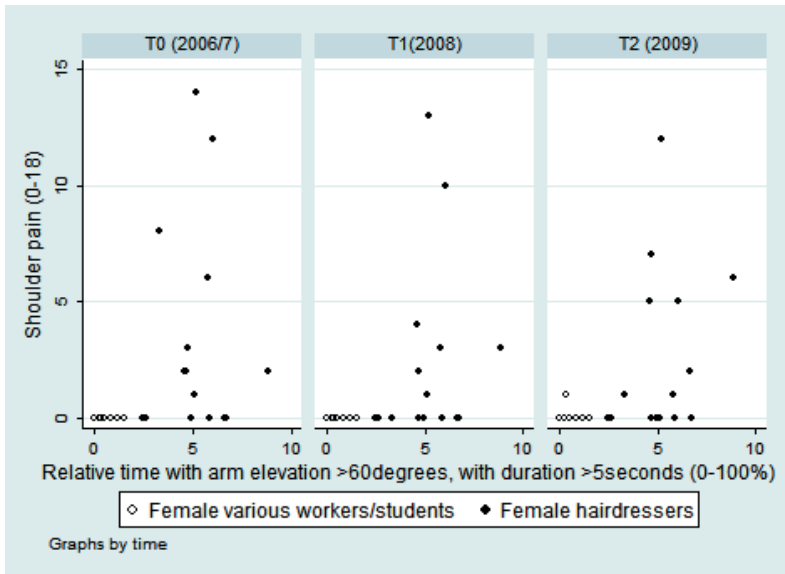


Figure 11. Shoulder pain at T0, T1, T2 and the association with relative time with elevated arms $>60^\circ$ with a duration of >5 seconds, among women (n=23)

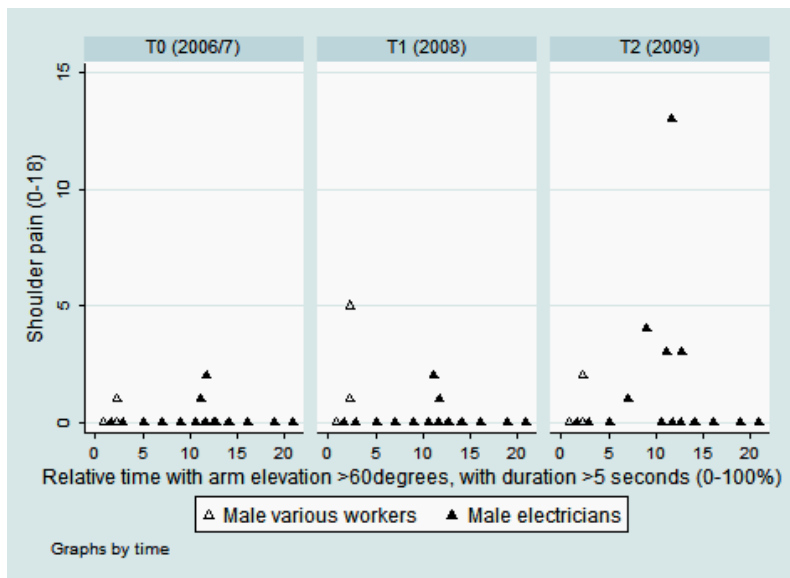


Figure 12. Shoulder pain at T0, T1, T2 and the association with relative time with elevated arms $>60^\circ$ with a duration of >5 seconds, among men (n=18).

Supplementary analyses

In the current dissertation the three papers are in many ways linked as they are all based on samples from the same cohort and based upon three different methods of quantifying the mechanical workload. Some supplementary analyses are included to increase the understanding and to link the results from the three papers together.

Correlation between the 3 mechanical workload measures

The Spearman correlations between the three different methods of quantifying mechanical workload were assessed on a subsample of 43 participants at T14. Results show that there was a statistical significant correlation between self-reported mechanical workload and the objectively measured workload assessing prolonged work with arms elevated $>60^\circ$ ($\rho: 0.52$ $p<0.001$) (See Figure 13). There was however no significant correlation between self-reported mechanical workload and objectively measured sustained trapezius muscle activity during work ($\rho: 0.15$ $p=0.34$) (See Figure 14). No statistical significant correlation was found between the two objectively measures; sustained trapezius muscle activity and working with arms elevated $>60^\circ$ ($\rho: 0.21$ $p=0.20$) (See Figure 15).

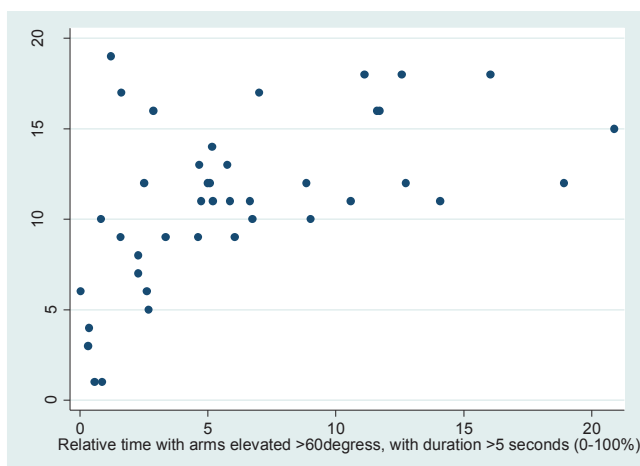


Figure 13. Correlation between self-reported mechanical workload (0-24) and the more specific workload of working with arms elevated $>60^\circ$ (0-100%) ($n=41$).

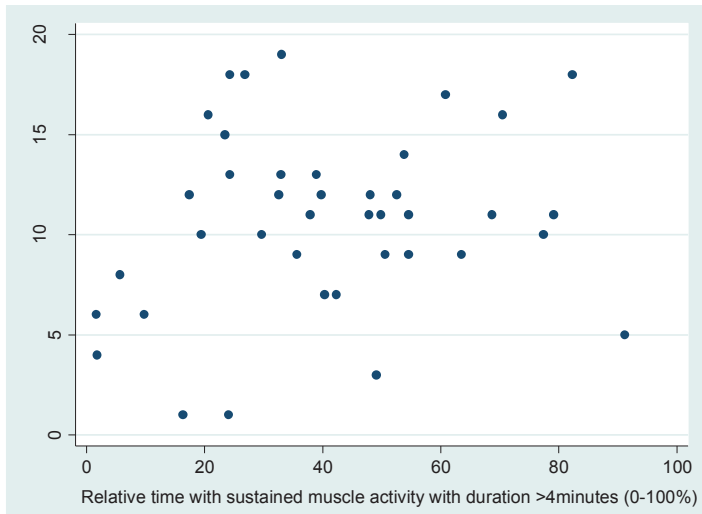


Figure 14. Correlation between self-reported mechanical workload (0-24) and the workload measuring sustained trapezius muscle activity during work (0-100%) (n=40).

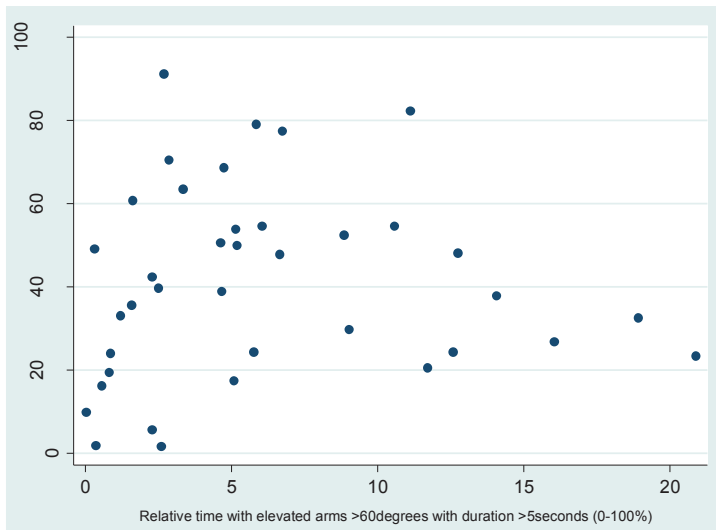


Figure 15. Correlation between the workload measuring sustained trapezius muscle activity during work (0-100%) and working with arms elevated $>60^\circ$ (0-100%) (n=38).

Correlation between pain reported in different body regions

In our three papers pain in the neck and shoulder region was investigated. It was chosen on the basis of being the most frequently reported pain in addition to the plausible association with mechanical workload of the upper extremity. Data on low back pain, arm/hand/wrist pain and hip/knee/leg pain was also collected at the same time as neck and shoulder pain in our cohort. Pain in the other regions were also calculated by multiplying pain intensity (0-3) and pain duration (1-4) giving a pain index ranging from 0-12. Cross sectional analyses using Spearman correlation between pain in the 4 different body regions were done and reported in Table 2. There are statistically significant associations between the pain reports in all 4 body regions.

Table 2. Cross-sectional correlation between the pain reports from different body regions from baseline T0 (N=420)

	Neck/Shoulder pain	Low Back pain	Arm/hand/wrist pain	Hip/Knee/Leg pain
Neck/Shoulder pain	1.00	0.43*	0.33*	0.34*
Low Back pain		1.00	0.17*	0.36*
Arm/hand /wrist pain			1.00	0.26*
Hip/knee/leg pain				1.00

* Correlation is significant at the 0.01 level (2-tailed)

To get an overview of the different body regions with musculoskeletal pain, a median yearly pain measure was made. The 21 time points were divided into seven periods/year's Y0-Y6. Year 0 (Y0) included pain reports from T0, T1 and T2, while Y1 included pain reports from T3, T4 and T5. Year 2 (Y2) included T6, T7 and T8 and Y3 included T9, T10 and T11. Year 4 included pain reports from T12, T13 and T14 while Y5 included T15, T16 and T17. Finally year 6 included T18, T19 and T20. The median of the three pain indexes reported in the three

time points in each year, made up the pain index (0-12) for that year. This was done for all the four different musculoskeletal pain regions. The index was then for illustrative purposes categorized into no pain (index=0) and three different levels of pain; mild pain (index=1), moderate pain (index=2-3) and moderate/severe pain (index=4-12). Figure 16 shows that neck and shoulder pain and low back pain is the most prevalent pain regions. The figure also shows an increase in moderate/severe pain in all four body regions over the study period.

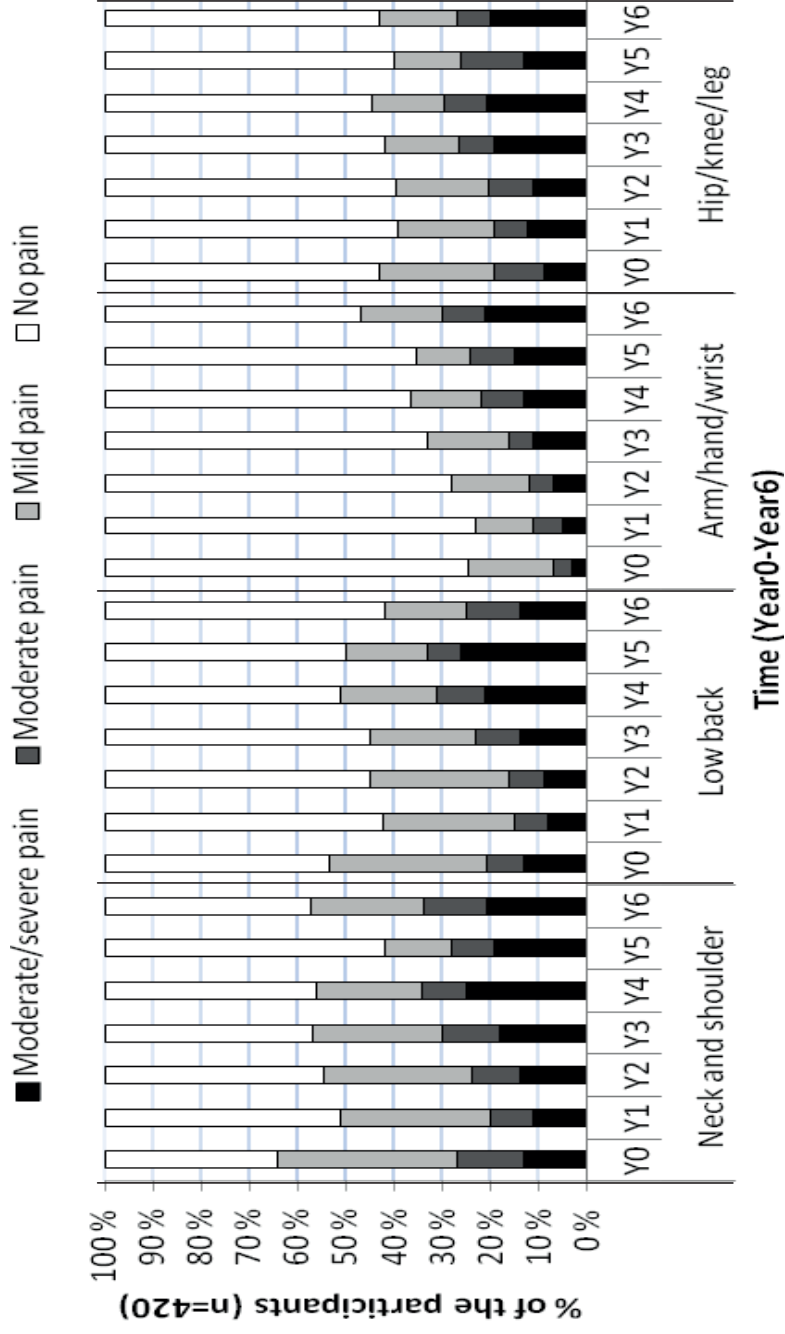


Figure 16. Pain in the 4 different body regions over the study period based on the pain index 0-12. Percent of the participants with no pain (index=0), mild pain (index=1), moderate pain (index=2-3), moderate/severe pain (index=4-12). (n=420).

DISCUSSION

This dissertation focuses on neck and shoulder pain among a cohort of young adults during their transition from technical school to working life. The three papers show low levels of neck and shoulder pain severity among the young workers, especially among men. An increase in neck and shoulder pain was however seen during the period with increasing tendency towards moderate/severe pain levels.

The overall aim was to identify early risk factors for neck and shoulder pain among these young adults with special emphasis on mechanical workload. Results from this dissertation have identified that both self-reported mechanical workload and objectively measured arm elevation during work may be early risk factors for neck and shoulder pain, especially among women. Perceived muscle tension habits and objectively measured trapezius muscle activity during work were also found to be early risk factors for neck and shoulder pain among this group. Even though the effects are relatively small, they may still be of importance when considering the populations young age and the short exposure time to work-related factors.

Methodological considerations

The prospective design is one of the methodological strengths in all the three papers of this dissertation. Extending the observation beyond a single moment in time gives the opportunity to detect changes and developments in both the exposure and outcome variable. This is beneficial compared to cross-sectional studies as it can be used to establish sequences of events which fulfills one of the formal criteria's of causation; temporality (Hill, 1965). At the moment more and more studies attempting to identify risk factors for neck and shoulder pain have a longitudinal design. There is however considerable differences in the length of follow-up and the number of measurements during the follow-up period. Compared with other prospective studies, we have a relatively long follow-up time of 6.5 years, with more frequent measurements than what is commonly used. This may be considered a methodological strength but at the same time it results in high dropout/loss to follow-up which increases the probability of selection bias. There are many difficulties associated with following a group of

people over a long time, and a longitudinal study like ours has many methodological challenges. By evaluating the sources of potential bias in our three papers the validity of the results are largely determined. Bias is often used to describe any systematic error in a study that can lead to incorrect estimates of associations, meaning that the observed study results will tend to be inaccurate and differ from the "true" results (Rothman et al., 2008). The literature distinguishes between three main types of biases that are important to be aware of in epidemiological studies; information bias, confounding and selection bias (Delgado-Rodriguez and Llorca, 2004).

Reflections regarding the internal validity

Information bias:

Outcome measurement: Pain

In all three papers we have used self-reported measures of the outcome; neck and shoulder pain. In Paper I and II we evaluated both the intensity and duration of the perceived pain in an attempt to grade the severity of the complaint. In Paper III we evaluated shoulder pain by the number of squares marked in the shoulder region on a pain drawing to grade the intensity of the complaint, disregarding the duration. It can be challenging to quantify pain in a clinically meaningful way as participants have different understanding of what pain is and different threshold when interpreting pain. Pain is an example of a measure that shows good repeatability, but there can be great uncertainty of its validity. The neck and shoulder pain measure used in this dissertation show good reliability (Steingrimsdóttir, 2005). It can nevertheless encompass different aspects of pain including discomfort, minor aches, complaints, or specific diagnosis, disabling pain and more serious medical conditions. The results show low levels of pain reports in all three papers, and this may indicate that the outcome in this dissertation reflects more of the complaint aspect of pain than disabling pain. It can also be a result of the fact that the questions used to measure pain, has been designed, and adopted among the adult working population (Christensen and Knardahl, 2010; Steingrimsdóttir et al., 2005; Steingrimsdóttir et al., 2004; Strøm, 2010), and therefore is insufficiently sensitive to pain reports among the young cohort in our study. Earlier studies

using the same method have however found similar low complaint levels among working populations as in our cohort (Steingrimsdóttir, 2005; Strøm, 2010). Using pain as an outcome variable among a working population is debated as the pain levels often are low and the clinical relevance is therefore difficult to evaluate. We could have used several alternative health parameters as outcome in example; the participants functioning level, work productivity, sick leave or work ability index. Nevertheless all measurements have their limitations and an important argument for using pain, is that it is a widely used health outcome when evaluating the possible effects of exposure to mechanical workload. It makes it easier to compare the results with similar studies which are important when drawing conclusions from our results.

There were also alternative pain measurements we could have used as there is a plethora of literature about the measurement of pain experience (Strong et al., 2014). Two relevant alternatives was the visual analogue scale (VAS) and the standardized Nordic questionnaire which are both validated (Kuorinka et al., 1987; Price et al., 2008) and extensively used in the scientific literature. However they both disregard the impact of the duration of pain. The disadvantage by only evaluating pain intensity is that the precision of the measurement may be reduced. It could introduce detection bias, as the researcher loses the ability to discriminate between those who experience high levels of pain only for a short period of time to those experiencing high levels of pain every day. More importantly when assessing pain among the young adults in our cohort it was essential to discriminate between those who experience minor complaints lasting over a long time (days and weeks) to those experiencing minor complaints for a day or two. The exposure to mechanical workload in our study was hypothesized to lead to low intensity complaints that may last either over a long or a short period. The ability to discriminate between differences in duration was regarded as important and it was therefore essential to use a method that incorporates both the intensity and the duration of the pain. This pain measurement provides benefits but there are also some drawbacks as it can lead to non-differential misclassification due to the sensitivity of the duration*intensity index. This means that small changes in either duration or intensity will lead to relatively large changes in the index and does not discriminate between those who experience high levels of pain only for a short period of time (acute pain) to those experiencing low levels of pain every day (chronic pain). This can be problematic as the risk factors for acute and chronic pain might be different. With regards to the purpose of the study

we found it nevertheless to be most appropriate to incorporate the duration aspect of pain as we were expecting relatively low levels of pain among the cohort of young adults.

How the participants recall their neck and shoulder pain is an important factor in regards to validity of the pain measurement. The recall of pain may be modified by several factors like emotions, pain at the time of report and the length of period to recall (Eisenhower et al., 1991). There is a high inaccuracy in the recall of pain (Erskine et al., 1990), and it is argued that recall bias is more likely to occur in methods using long recall periods (Eisenhower et al., 1991). Results from a retrospective study showed that participants could recall the severity of the pain for a period of three months (Brauer et al., 2003). Another study showed that pain reports are heavily influenced by the current symptoms (Miranda et al., 2006). To reduce the influence of recall bias we used a 4 weeks recall period in the outcome variable in all three papers.

We chose to measure pain approximately every 4th month in Paper I and II and every year in Paper III to monitor changes in pain reports over time. Frequent measurements of pain reports over the follow-up period was regarded as essential knowing that neck and shoulder pain fluctuate over time (Steingrimsdóttir et al., 2004). Using a fixed time interval between the measurements was done to have the possibility to evaluate different time-lags between the mechanical exposure and neck and shoulder pain. The use of repeated pain measures in Paper I revealed that the participants reported high pain levels at baseline compared to the follow-up reports. A similar finding has been shown in a longitudinal study with repeated pain measures among post-office workers (Steingrimsdóttir et al., 2004). This may be explained by the difficulty of understanding the questions or an increased attention to complaints at the first encounter to these questions. Another reason might be that the participant's gives answers in the direction they perceive are of interest to the researcher (obsequiousness bias) (Sackett, 1979). Even if there is a bias in this high initial pain report level it is minimized by the use of repeated measurements of neck and shoulder pain in our cohort.

Exposure measurement: Mechanical workload

A systematic review of studies concerning the association between mechanical workload and neck shoulder pain found that they all share some common limitations including crude

exposure measures and small sample sizes (Mayer et al., 2012). During the work with this dissertation it was evident that this was methodological challenges that were difficult to get around. In Paper I, we measured self-reported mechanical workload several times during the follow-up period among the whole cohort. In contrast, Paper II and III are based on objectively measured mechanical workload assessed only at one time-point during the study period and only among a subsample of the cohort. This indicates also that there are differences in possible information bias in the three papers.

In Paper I, both the outcome and exposure were gathered by self-reports, giving a possible measurement error. The reports may be influenced by personality dimensions such as negative affectivity which can deflate or inflate the associations (common method bias) (Podsakoff et al., 2003). The participants can also recall their mechanical workload differently based on their neck and shoulder pain experiences (recall bias). If the presence of neck and shoulder pain influences the perception of their mechanical workload it will produce differential misclassification and lead to spurious results. By designing the questionnaire so that the work-related factors were answered in the beginning while the questions on neck and shoulder pain were placed at the end, the bias may have been reduced. Another way we attempted to minimize this bias was to control for the pain reported at baseline.

The self-reported mechanical workload used in Paper I has shown acceptable test - retest stability and good internal consistency (Balogh et al., 2001). Still, some of the 12 questions included in this measure might not be sufficiently relevant for the development of neck and shoulder pain, as it referred to postures for back, as well as lifting, use of vibrating tools and work involving kneeling and lying. It would perhaps be more accurate with questions that only concentrated on the workload related to neck and shoulder area.

The participants were asked “Does your work involve..?”, without having a retrospective time frame for the different work postures (e.g. last week, month, year). The alternative answers did not give any accurate duration of the time spent in each work posture (e.g. >30minutes pr day or <30 minutes per day). This can give rise to information bias as it runs the risk that the participants interpreted the question differently. It has been stated that self-reported mechanical workload have low validity compared with direct technical measurements of work postures (Hansson et al., 2001). It is however important to keep in mind that the objective exposure measurement is not always regarded as a “gold standard”, it depends on what aspect

of mechanical workload that is studied. In Paper I we wanted to evaluate the mechanical workload of the upper extremity broadly and the self-reported values were regarded as accurate enough. However if the aim was to evaluate a specific mechanical workload e.g. work with arms elevated the objective measures are recommended. As experienced during the work with this dissertation there is always a trade-off when prioritizing between the level of accuracy in the exposure measurement and the possibility of repeated exposure measurements and a larger sample size.

In Paper II the mechanical workload was assessed using surface electromyography (sEMG) on the upper trapezius muscle. It is an objective measurement of the muscle activity during work. Even though it is an objective measurement it is debated if EMG measurements are valid for evaluating mechanical workload, as the muscle activity are influenced by the individual muscle tension habits, postural motor habits as well as mental workload. Judging from the results of the supplementary analyses of the correlation between the three mechanical exposure measures, it is most likely that the EMG measurement covers a slightly different aspect of work-related exposure than the inclinometer measurement and the self-reported mechanical workload measurement. According to an analyze of a subsample from the current cohort it was found an association between trapezius muscle activity measured by electromyography (EMG) at work (especially during the breaks) and perceived muscle tension (Wærsted et al., 2012). This might suggest that the EMG measurement is more sensitive with respect to capturing a subject's muscle tension habits compared to the mechanical workload. The validity of the upper trapezius muscle activity during work as a measure of mechanical workload can be considered as relatively moderate in this study and is important to take into account when concluding on the results.

In Paper III the mechanical workload was assessed using inclinometer where the participants arm postures during work was measured. This technical measurement collected arm posture continuously during a whole working day. Direct technical measurement to assess mechanical workload is by many regarded as a "gold standard" for the true exposure, there are however some methodological limitations. In both Paper II and III the work-related exposure were only assessed during one day for each participant, not evaluating if the mechanical exposure changed over the follow-up period and not assessing the exposures in the past or during leisure time. This limits the information on average exposure during a week, month and also lifetime exposure. This cohort consists of young adults and very few have had earlier work

exposures that are of relevance, the lifetime exposure is therefore not a likely a source of bias. In regards to the objective measurements in both Paper II and III, conditions like heat, cold, dust, noise, and extreme postures like crawling could have influenced the measurements, limiting the measurements or potentially damaging the equipment and introducing information bias. The effect the equipment may have had on the participant's ability to conduct their ordinary work tasks was also a possible source of bias. Fourteen of the subjects participating in the technical measurement reported that the technical equipment had influenced their work. One stated that it triggered a lot of questions from customers, another reported that it had been a little uncomfortable and one participant said the equipment was a hindrance for some movements. Others thought it was a bit irritating in the long run, but that it had no major effect on their work, indicating that this was not a relevant source of bias.

Confounding:

Identifying and controlling for potential confounding variables has been important both in the planning- and analyzing phase of these three papers, as confounding is a common source of error in medical research. A confounder is a variable which may cause spurious associations between the exposure and outcome it may also over- or under estimate the effect. The confounder is a moderator and differs from a mediator as it is not part of the causal pathway between the exposure and outcome. It is looked upon as a third variable which is a common antecedent to both the exposure and outcome (Rothman et al., 2008). One of the conditions necessary for confounding to occur is that the confounding factor must be distributed unequally among the groups being compared. Consequently, one possible way of preventing confound is the use of restriction. This involves selecting a group of subjects who have the same levels of the confounding factors. In our study we restricted the study group to include only those attending the second year of technical school. This was done to exclude those in upper secondary school presumably minimizing an effect of socioeconomic status and to have a homogenous age among the study group. Another strategy employed for avoiding confounding is during the data analysis. In this dissertation this was done by stratification and using multivariate models (Rothman et al., 2008).

Identifying confounders:

In this dissertation the identification of possible confounding factors was done by finding the variables that are theoretically related to the outcome variable. If the scientific literature also showed that potential confounding variables were associated with the exposure variables they were regarded as confounders. This is a commonly used strategy. The use of directed causal diagrams (DAGs) can facilitate the identification of the confounding factors and help in understanding these often complex structures (Rothman et al., 2008), however in this dissertation DAG's were not used in a systematic manner.

Gender is an example of a commonly identified confounder. The treatment of gender has been widely discussed in research on musculoskeletal disorders (Messing et al., 2003), as several studies show gender differences in pain reports (Hooftman, 2008; Juul-Kristensen et al., 2004). There are at the same time studies indicating that the mechanical workload differs between the men and women (Côté, 2012; Hooftman et al., 2009). The discussion is whether to stratify by gender or control for gender in the multivariate analyses. In all three papers of this dissertation there was found a gender difference in pain reports as women reported more pain compared to men. In all the three papers we stratified for gender. However in Paper II and III, the stratification resulted in small groups which made it difficult to give gender specific conclusions. In the multivariate analyses including both men and women gender was regarded as a confounding factor and controlled for. The other confounders identified in the three papers were included in the multivariate analysis and controlled for in that way. Still, there is always a possibility for residual confounding, which means that there could have been confounding factors of importance that we did not measure or control for.

Over adjustment:

A variable should only be controlled for if it is a confounder (Hernán et al., 2002), and there might however be sources of over adjustment in the three papers of this dissertation. One might for instance question the adjustment for previous neck and shoulder pain in Paper II and III. Similarly the adjustment of baseline neck and shoulder pain in Paper I can have resulted in an underestimation, dismissing the effect of earlier mechanical exposure on pain. It

may at the same time be considered unlikely as these participants had very little earlier work exposure. In Paper II and III we have adjusted for self-reported mechanical workload in the multivariate analysis. This might be criticized for leading to an over adjustment, underestimating the effect of arm elevation on shoulder pain in Paper III.

Reflections regarding the external validity

Selection bias:

Non-responders,

The external validity decreases with increasing differences in relevant variables between the study sample and the population they are suppose to represent. It is often assumed that a high response rate indicates higher generalizability. It is evident that low response rates can indicate selection bias, however a low response rate does not always indicate low generalizability, as does not high response rate indicate higher generalizability (Visser et al., 1996). The results representativeness should be based on more than the response rate. Assessing the possible reasons way some participants do not respond may be of importance.

In Paper I, the participation rate at baseline was 85%, which is relatively high considering the young age of the population studied. It may be explained by the fact that the questionnaire was completed during school hours. The non-responders comprised of either those not attending school on the day of the measurement or those who did not return parental informed consent (which was required for participants <18 years of age). It is therefore considered unlikely that the non-responders introduced a selection bias in Paper I, which strengthens the external validity of the results.

In Paper II and III, the participants were a subsample of the larger cohort (10% of the cohort was in the subsample). Methodologically it would have been ideal to do the technical measurements on the entire population, but based on the resources and time available we only did it on a subsample, possibly reducing the external validity of the results in both Paper II and III. The sampling procedure was identical in the two papers; those who lived and worked

in the Oslo area were contacted by telephone. This telephone sampling may have led to a lack of accuracy as some were not reached and some had moved away from the Oslo region. This sampling procedure could be perceived as a convenience sample where those easiest to recruit were included. However during the sampling procedure we considered the participants' educational background and gender in an attempt to include those subjects that were more likely to be representative of the entire population. Nevertheless, the participants included were self-selected and could have introduced a bias as voluntary participants in a research study often differ from those who do not accept participation (Rothman et al., 2008). Analyses on the baseline data showed no significant differences in background and outcome measures between the two groups (except for the significant lower tobacco use prevalence among the subsample). This may indicate that non-participation bias did not constitute a major problem in Paper II and III.

Studying young workers may reduce the healthy worker effect

It was a strategic decision to recruit technical school students who had minimal previous exposures to mechanical workload and to follow them in their transition to working life where they were increasingly exposed to a variety of work-related exposures. One of the methodological challenges when identifying risk factors in an occupational setting is that studies conducted within a well established workforce may comprise those individuals least likely to have an adverse outcome from exposure. This is due to workers who become ill changing their job or job conditions, thus leaving a relatively healthy workforce. This selection bias may lead to an underestimation of the risk of neck and shoulder pain since exposures and outcomes will be under-represented by such a cohort (Arrighi and Hertz-Picciotto, 1994). Our design minimizes the possible healthy worker effect as we follow them their first years of working life and regardless of changes in their occupational status, thus strengthening the validity of the results.

Loss to follow-up,

All the three papers in this dissertation suffer from loss to follow-up. In Paper I the loss to follow-up after 6.5 years was 54% while in Paper II and III 15% of the participant were lost to follow-up after 2.5 years. Bildt and colleagues found in 2001 that the dropout rates in longitudinal studies on musculoskeletal disorders ranged from 7% to 57% (Bildt et al., 2001).

The length of time the cohort is followed and the number of follow-ups during this period has been found to have an impact on the dropout rate (Zunzunegui et al., 2001).

The high loss to follow-up in Paper I can be a result of the long follow-up time and the frequent measurements during the follow-up period. In addition it is important to keep in mind that the cohort consists of young adults which is a group that often are difficult to motivate and track over time. There could be numerous reasons for the loss to follow-up, one example being that people move and we lose contact with them. If the participants are lost randomly it will less likely create a loss to follow-up bias, however if the loss to follow-up are associated with both exposure and outcome the external validity of the results may be affected. Analyses done on the data from baseline showed no significant differences in neck and shoulder pain or self-reported mechanical workload between those remaining after 6.5 years (n=193) and those lost to follow-up (n=227). Although the two groups were comparable with respect to outcome and exposure at baseline, they could have very different pain levels during the follow-up period. It may be that those lost to follow-up had more neck and shoulder pain during the follow-up period compared to those who responded and thus creating a non detectable selection bias. In an attempt to illuminate this uncertainty an attrition analyses was done on the study cohort (N=420) (Svenssen, 2011). The result showed that participants with background as student hairdressers and student electricians had significantly more missing than media/design students. Male participants had significantly more missing compared to females, as did none-western participants and tobacco users. It is therefore likely that the missing in this dissertation is dependent on the observed data; hence the missing is not completely at random. Neck and shoulder pain and self-reported mechanical workload, showed no significant correlation with the missing data (Svenssen, 2011). It can therefore be argued that the missing were not systematical in regards to the outcome and the mechanical exposure variable. This limits to some extent the probability of selection bias due to the loss to follow-up and strengthens the external validity of the results in Paper I.

Imputation of missing data

Even though the missing data in our cohort is characterized as missing at random and therefore less problematic than selective loss, all missing data reduces the representativeness of the sample. It also decreases the sample size of the study which in turn leads to more uncertain estimates and wider confidence intervals. Several different missing data-handling

methods are available. The most frequently used are the complete-case analysis (CCA) (Eekhout et al., 2012). However this method is best suited when the missing data are completely at random (MCAR), which is most likely not the case in our cohort hence using complete-case analysis would lead to selection bias. To reduce the bias introduced by the missing data single or multiple imputation methods are used. The multiple imputation method, used in the three papers of this dissertation, is argued to be preferred as it gives reliable and unbiased results even if the missing data are missing at random. It also takes missing data uncertainty into account (Janssen et al., 2010; Little and Rubin, 2002). The validity of results from multiple imputations depends largely on the variables used when modeling the imputation. Multiple imputation analyses will avoid bias only if enough variables predictive of missing values are included in the imputation model (Sterne et al., 2009). In each of the three papers in this dissertation a separate imputation model were developed and in all models the variables used in the multivariate analyses were included. The number of imputations used is also of importance. In all three papers 5 imputed datasets were generated. For many practical purposes, 2 or 3 imputations capture most of the relative efficiency that could be captured with a larger number of imputations. It has been argued that even a small number (5 or fewer) of repeated imputations enormously improves the quality of estimation and gives valid inference (Rubin, 1996). In all three papers we have used 5 imputed datasets which we argue is sufficient and improves the representativeness of the results. However, a too-small number of imputations can lead to a substantial loss of statistical power, and some scholars now recommend 20 to 100 or more (Graham et al., 2007).

In longitudinal studies like this the response rate, the loss to follow-up, how missing data is treated as well as the sample size is important to emphasize when interpreting the external validity. On this basis, Paper I may be regarded as having a relatively good external validity and most representative of the target population, as it has a high response rate (without indications of selection bias), moderate loss to follow-up (where those lost to follow-up does not considerably differ from the once remaining in the study) and a relatively large sample size. Paper II and III however can be regarded as having somewhat lower external validity as they are a subsample of the target population (even though there are no indications for selection bias), low number of loss to follow-up and a small sample size.

Could the findings from these three papers still apply to populations beyond those included in this dissertation? The population in this study was selected from 13 technical schools in the

Oslo area. They are therefore not necessarily geographically representative of all technical students in Norway. It is not evident that there is huge geographical differences among technical school students in Norway suggesting that the findings may apply for young adults in the transition from technical school to working life. However, during the study period they were followed into working life and ending up working as hairdressers, electricians and a group working in a variety of occupations. The generalizability of the results to the specific occupations is therefore considered as limited.

Discussion of main findings

A consistent result in all three papers was the low level of neck and shoulder pain severity reported. This is not surprising when we consider the participant's young age, as low levels of pain in a cohort of healthy adults should be expected. The low pain severity levels may however have reduced the possibilities of detecting differences. There were still detected interesting associations in all three papers, even though the effects can be regarded as small to moderate. Despite these low pain severity levels, a significant increase of neck and shoulder pain among this cohort in their first years of working life was found, showing an increased tendency towards moderate/severe pain. The increase in pain and the associations between mechanical workload and neck and shoulder pain found in this dissertation may indicate that risk factors early in working life may be of importance. However, adolescence and early adulthood is a period characterized by biological, psychological and psychosocial changes, also likely to affect the experience of health problems and pain (Schwarzer et al., 1997). The increase in pain found can also demonstrate the effect of time consistent with the knowledge that pain increases with age (Vikat et al., 2000). The supplementary analyses showed an increase in pain severity also in the other body regions in this period. Pain reports were also found to be interrelated which complicates evaluating single risk factors and their impact on a specific body region. It is therefore not straightforward to interpret the finding and suggests that there may be several factors that are important in the increase of neck and shoulder pain among this group of young workers.

Reflections on variables associated with neck and shoulder pain

Self-reported mechanical workload and objectively measured arm elevation during work;

One of the interesting findings in this dissertation was that mechanical workload both using subjective (Paper I) and objective measures (Paper III) were associated with neck and shoulder pain among the cohort, significantly among the women. Both papers showed the same tendency even though there are methodological differences between them. These results add to the already growing longitudinal literature on the association between mechanical workload and neck and shoulder pain (Mayer et al., 2012). It is however important to point out that there is tremendous differences in what is defined as mechanical workload. The exposure can include repetitive work, vibration, work with hands above shoulder level, work in awkward postures, heavy lifting, pushing and pulling, squatting, static posture, lifting and manual handling, forceful work and working with a flexed or rotated neck (Mayer et al., 2012). This list illustrates the differences in specifying the exposure and it also identifies the difficulty when comparing the findings. Paper I and III in this dissertation also differs in the specification of mechanical workload. Paper I found that self-reported mechanical workload assessing a wide range of different aspects like postures, lifting, vibration and repetitive movements were associated with neck and shoulder pain. Other studies assessing self-reported mechanical workload using questions on a wide range of different postures and movements have also found significant associations with neck complaints (Luime et al., 2004) (Sterud et al., 2014). Others find non-significant but positive associations with neck and shoulder complaints (Feveile et al., 2002; Hoozemans et al., 2002), and there are also studies reporting the opposite (Grooten et al., 2007). The discrepancy in results may partly be explained by the different questionnaires used to assess the mechanical workload. Some are based on a single question and the validity and reliability may not be assessed. There could also be difference in associations in young working populations versus middle aged and older workers. Few studies have focused on young workers in particular, however a longitudinal study on newly employed workers showed a significant association between repetitive arm movements and shoulder pain (Harkness et al., 2003). This may indicate that self-reported

mechanical workload might be a risk factor also early in working life. The associations found in Paper I contributes to this interpretation.

The associations found in Paper I are however not easily comparable to the findings in Paper III, where we have used an objectively measured exposure of a more specific awkward posture; sustained work with elevated arms. The subjective and objective measure might however be considered to overlap in some extent as one of the aspects of self-reported mechanical workload is work with arms elevated. The supplementary analyses showed that this was the case in this cohort, as a significant correlation between the two exposure measures were seen. We found in Paper III that work with prolonged arm elevation $>60^\circ$ were associated with shoulder pain among the young adults in our cohort. There are several studies with longitudinal design assessing work with arms elevated (Harkness et al., 2003; Leclerc et al., 2004; Luime et al., 2004; Miranda et al., 2001). Not all found significant associations with neck and shoulder pain however they all show positive associations. It is however very few studies assessing different durations of arm elevation without pauses and its possible effect on neck and shoulder pain. The identification of how high and how long the arms must be elevated before the harmful effects occur is something of great importance in clinical and preventive settings. To assess this one needs to use objectively measures of arm elevation during work. The use of objectively measures when evaluating work with arm elevation is however sparse, especially encompassing a longitudinal design. Punnett and colleagues (2000) used video recording when assess arm elevation among automobile assembly workers (Punnett et al., 2000). They found that working 10% of the work day with elbows over shoulder height constitutes a risk for shoulder disorders. Svendsen and colleagues (2004) published a paper on objectively measured arm elevation and showed an association with shoulder disorders (Svendsen et al., 2004a). Neither of these studies had a prospective design, and the underlying causality of the associations could not be verified. Both however included the temporal aspect of the mechanical workload assessing the relative time working with arms elevated implying the importance of the duration of exposure. Svendsen and colleagues takes the temporal aspect a step further also assessing the association between the length of periods of arm elevation without pauses and shoulder disorders. This is the same aspect of prolonged arm elevation that we highlight in Paper III where we assess the periods with arm elevation lasting >5 seconds without pauses. These two studies highlight the importance of the duration of the mechanical exposure and suggest that the duration of arm elevation without pauses

should be investigated further. The results from this dissertation contribute to the already existing knowledge that work with arms elevated are associated with neck and shoulder pain and it also reveals that exposures to arm elevation is important also at an early stage of working life. A cross-sectional study has shown that work above shoulder level was associated with degenerative alternations of the rotator cuff tendons using magnetic resonance imaging (MRI) (Svendsen et al., 2004b). A newly published longitudinal study found an increasing risk of surgery for subacromial impingement syndrome with increasing shoulder load at work (Svendsen et al., 2013). This is similarly found in a nationwide register study where cumulative exposure to arm elevation at work was associated with an increasing risk of surgery for subacromial impingement syndrome (Dalbøge et al., 2014). Even though the young workers in this dissertation have low cumulative exposure to arm elevation at work and report low levels of pain severity the findings from these three studies indicates the importance of targeting those with high levels of shoulder load at an early stage to prevent future pain and surgery.

Self-reported muscle tension and objectively measured muscle activity during work; Results from the current dissertation show that both perceived muscle tension (Paper I) and objectively measured muscle activity during work (Paper II) were positively associated with neck and shoulder pain among this cohort of young adults. The objectively measured muscle activity (EMG) was initially included as a measure of the participant's mechanical workload. The supplementary analyses however showed low correlations with both objectively measured arm elevation during work and the self-reported mechanical workload indicating that this measure may capture something more than only the mechanical workload. This is however not surprising as the upper trapezius muscle has been shown to be responsive to mental influences by both recent (Willmann and Bolmont, 2012) and older studies (Wærsted and Westgaard, 1996). In this dissertation results from Paper II indicates that sustained trapezius muscle activity with periods lasting >4 minutes for more than half of the working day increases the rate for neck and shoulder pain. This can be interpreted as an association between mechanical workload and neck and shoulder pain. It can also illustrate an association between the individual muscle tension habit and neck and shoulder pain. Furthermore it can be interpreted as an association between the mental aspects of work (the psychological and social work factors; job conflict etc.) and neck and shoulder pain. A study among females in service occupations found that their reported general tension was associated with the presence

of psychosocial distress (Holte et al., 2003). Increased strain and subsequently increase muscle tension may put individuals at a greater risk for developing neck and shoulder pain. There has also been done a longitudinal study of young adults (aged 15-18) demonstrating that psychosomatic stress symptoms resulted in an increased risk of developing neck and shoulder pain 7 years later (Siivola et al., 2004). Several studies have also highlighted the importance of psychological and social work factors on the development of neck and shoulder pain (Ariëns et al., 2001a; Bongers et al., 2002; Christensen and Knardahl, 2010). Most possibly there is a mixture of mechanical workload, mental workload and individual muscle tension habit that is reflected through the EMG measure, which makes it an extremely difficult exposure to interpret. The association between trapezius muscle activity during work and neck and shoulder pain has shown inconsistent results. Several recent studies have found a lack of association between neck and shoulder pain development and muscle activity (Mork and Westgaard, 2006; Nilsen et al., 2006; Strøm, 2010; Westgaard et al., 2001). Upper trapezius muscle activity during work has been extensively studied, however most studies have used a slightly different method of quantifying muscle activity compared to the method used in this dissertation. Static muscle activity and the average time of sustained muscle activity are both EMG measures that are commonly used assessing the association with neck and shoulder pain (Aarås, 1994; Finsen et al., 1998; Sandsjö et al., 2000; Thorn et al., 2007). These methods differ from our methods as they do not take into account the temporal aspect assessing the length of periods of muscle activity without pauses. This may explain some of the inequalities of results. A study which also considers the time with periods of muscle activity without pauses during work found a positive association with neck and shoulder pain (Østensvik et al., 2009a), similarly to our findings in Paper II. Both included the temporal aspect of the muscle activity suggesting that the duration of muscle activity without pauses might be of importance in relation to neck and shoulder pain.

In an analyze of a subsample from the current cohort it was found an association between trapezius muscle activity measured by electromyography (EMG) during work and perceived muscle tension. This association was more pronounced when the analysis of the EMG activity was limited to the pauses from work (Wærsted et al., 2012), which also is more sensitive with respect to capturing a subject's muscle tension tendency. In light of the results from Paper I, indicating an association between perceived muscle tension and neck and shoulder pain, it may be that it is the individual muscle tension habit that is mostly reflected through the EMG

measure. Perceived muscle tension has been suggested to act as a risk factor or intermediate factor for pain through its relation with muscle activity (Vasseljen et al., 1995). One can also argue that the neck and shoulder pain measure may have been interpreted as any form of uncomfortable somatic sensation including muscular tension. This seems unlikely in our study, but nevertheless it would mean that the exposure and outcome measured the same phenomenon and therefore was associated.

The gender difference in associations; Gender inequalities in work-related health outcomes are well documented, especially for pain and complaints in the neck and upper-extremity (Mehlum et al., 2006; Punnett and Herbert, 2000). This is in line with the findings from all three papers in this dissertation showing that neck and shoulder pain were more prevalent among women than men. An explanation for this gender difference is not established. There is however several theories, one suggesting that women may have a lower threshold for reporting neck and shoulder pain compared to males, it has however been shown that women are more likely to have their upper-extremity and neck complaints “confirmed” by a diagnosis in the affected region (Mehlum et al., 2013; Punnett and Bergqvist, 1999). This finding may suggest that it is the opposite of what is previously hypothesized, that in fact women may have a higher threshold of reporting pain compared to men. It could be that women experience their complaints relative to the level of symptoms among their colleagues. It could also be explained by the hypothesis that high mechanical work demands may be substantially more strenuous for women compared to men (Zetterberg et al., 1997). Knowing that women on average have lower muscle strength than men this vulnerability hypothesis could also be a potential explanation (Hooftman et al., 2004). A study comparing upper body muscular load among male and female house painters performing identical tasks, showed that women had higher relative muscular load than their male colleagues (Meyland et al., 2014). Higher muscular load accumulated over years of work may in part explain why pain in the neck and shoulder region is more frequent among women. However it does not explain the gender difference in pain among young less exposed adults.

This dissertation also highlights gender differences in associations. Paper I and III shows significant associations between mechanical workload and neck and shoulder pain, mainly among the female participants. This is in contrast to the current literature (Mayer et al., 2012). However, some studies have only included male workers while other studies only have female workers in their cohort. Gender difference in the association between exposure to arm

elevation and shoulder pain is however found earlier. One longitudinal study found that self-reported exposure to work with arms above shoulder level were associated to the incidence of shoulder pain after 3 years, only among women (Leclerc et al., 2004). An association has also been seen among women in cross-sectional and case-control studies (Fredriksson et al., 2002; Nahit et al., 2001). One of the possible explanations for this difference in association by gender may be the low levels of pain among men in our cohort. In the analyses the low prevalence and severity of pain increases the uncertainty of the estimates and could lead to type II error, failing to detect a relationship. In Paper II the results indicate an association between sustained muscle activity and neck and shoulder pain which was found most consistent among the male participants. This shows an opposite gender difference in associations, indicating that men are more at risk for developing neck and shoulder pain when exposed to trapezius muscle activity. Interpreting the gender differences in this dissertation is however not straightforward as the difference in gender cannot be disentangled from the occupational differences. In combination with the low pain severity levels and the small sample size (especially in paper II and III), it limits the possibility to draw conclusion on the aspect of gender from these findings. The findings from this dissertation nevertheless contribute to the existing knowledge of gender difference in pain reports. The results also highlight the importance of large study samples enabling stratification by gender in future research.

Induction time/Latency period: The main aim of this dissertation was to identify early risk factors for neck and shoulder pain with special emphasis on mechanical workload. In the work with this dissertation it became evident that determining the impact of mechanical workload on neck and shoulder pain was difficult in many respects, one being the considerations of the “time lag” between the exposure and outcome. Determining the impact of the work-relatedness of an injury is regarded to be easier compared to evaluating the work-relatedness of e.g. musculoskeletal pain and disorders since there often is a longer period of time between the exposure and outcome. There are usually a period of time between the action of an exposure and the completion of a sufficient cause. In epidemiology research induction period is defined as the period of time beginning at the action of the exposure and ends when the final exposure acts and the disease occurs (Rothman et al., 2008). After the disease occurs, its presence is not always immediately apparent. It becomes apparent later and the time interval between disease occurrence and its subsequent detection (e.g. experiencing

symptoms) is termed the latent period (Rothman et al., 2008). In the development of musculoskeletal pain and disorders there can be difficulties distinguishing between the induction time and the latency period because there is no way of establishing the exact time of the start of a disease process. The term “time-lag” have been used instead (e.g. in Paper II in this dissertation), to express the time from exposure to the possible effect. This term is also used in a recent meta-analysis on occupational exposure and the relevance of time lags in longitudinal studies (Ford et al., 2014). In the planning of this study it was decided to measure the outcome; neck and shoulder pain approximately every 4 months while the exposure; self-reported mechanical workload were assessed approximately twice every year, while exposure to arm posture and trapezius muscle activity was measured only once. This decision was based on the knowledge that pain fluctuates over time and based on the lack of knowledge regarding the delay (time-lag) between the exposure and the development of neck and shoulder pain (Punnett and Wegman, 2004). Relationship between musculoskeletal disorders and work-related exposures are not easy to map as these factors often co-occur with common determinants and interact with each other (Punnett and Wegman, 2004). Musculoskeletal disorders may develop after weeks, months or even years of exposure. The time-lag required may therefore be dependent on the intensity of the exposure, but this is this is not been well documented (Punnett and Wegman, 2004). In Paper II the results suggested a short time-lag (≤ 6 months) between the exposure of sustained muscle activity and neck and shoulder pain. The results from a case-control study on neck and shoulder pain also purposed a short time-lag for exposure to work above shoulder level, while a longer time-lag was indicated for exposures to repetitive work with the hands and vibration (Fredriksson et al., 2002). A newly published register study on occupational shoulder exposure and shoulder surgery used cumulative exposure estimate for a 10 year time window with a 1 year lag time. They found a gradually increase in risk of surgery for subacromial impingement syndrome with the number of years of work with arm elevation (Dalbøge et al., 2014). There is nevertheless limited knowledge on the appropriate time frames for lagged effects. This has been stated in numerous studies over many years (De Lange et al., 2004; Ford et al., 2014; Punnett and Wegman, 2004). This lack of knowledge is reflected in the various designs of the studies concerning musculoskeletal pain. An increasing number of longitudinal studies are seen, however the time between the exposure and outcome measure varies considerably. Long follow-up time over several years are not uncommon, it is however often accompanied with only one or two measurements of exposure and outcome, meaning that there can be many

years between the exposure and outcome measurement. This is not always problematic but it needs to be pointed out since it is based on the assumption that implies either a stable exposure over time or a time-lag of several years. It can also be problematic with only one or two measures of the outcome as the pain reports are known to vary over time. This dissertation did not explore different time-lags regarding the development of neck and shoulder pain specifically. The frequently measured outcome and exposure showing the fluctuation in both variables over time (Paper I) may however contribute to highlight the importance of repeated measures and increase the awareness of the planning, analysis and interpretation of results. The lack of knowledge on time-lags does not invalidate the literature but raises uncertainty on how to utilize the available evidence. There is however a need for longitudinal studies to explore the concerns regarding different effects of different time-lags in the development of neck and shoulder pain. It has been suggested that a time lag of one year is enough (De Lange et al., 2004). It is nevertheless still a gap of knowledge that needs further exploration.

CHALLENGES FOR FUTURE RESEARCH

There has been a large number of studies examining neck and shoulder pain showing substantial evidence for etiologic importance of mechanical risk factors at work (Punnett, 2014). There is however still issues that are unresolved and methodological concerns that should be addressed when looking at the future perspective of this research area. Some of the challenges in future research may partly be the balancing between precision of the exposure and outcome assessments and the size of the study population. Our experience was that objective measures of exposure decreased the studies sample size, as it was too time consuming. However new measuring devices which are more time and resource efficient (Korshøj et al., 2014) could make it possible to increase the sample sizes in future studies.

Challenges can however also include deciding on an appropriate length of follow-up and how frequent the outcome and exposure assessment should be sampled. It is also difficult to determine precisely the onset of neck and shoulder pain in workers as most pain develops gradually and follows an episodic course throughout people's lives. This leads to the next challenge of determining the exact contribution of work to the onset of neck and shoulder pain. Also taking into account the multifactorial factors contributing to the development of neck and shoulder pain can pose a challenge.

The focus in this dissertation have been pain in the neck and shoulder, the supplementary analysis showed however that there was significant correlation between the pain reported from different body regions. This has also been found in other studies (Carnes et al., 2007; Coggon et al., 2013; Kamaleri et al., 2008). It complicates the interpretation of the results as the exposures found related to neck and shoulder pain might not be specific to the pain in only that region. It could be that the same mechanical exposure predicts multisite pain (Herin et al., 2014; Straube, 2014). We know that certain mechanical exposures at work are associated with painful conditions at particular anatomical site, there is however a lack of knowledge about the relationship between exposures at work and multisite pain. The study by Herin and colleagues in 2014, emphasizes that multisite pain in the working population is in need of more attention (Herin et al., 2014). This is also demonstrated by several studies indicating that multisite pain is a strong predictor of work ability and absence from work (Haukka et al., 2014; Haukka et al., 2013; Neupane et al., 2011). The exploration of this topic is not

addressed by the papers in this dissertation but the data from this cohort gives the potential to further investigate it in future papers.

Future research should focus on incorporating the multifactorial risk factors for neck and shoulder pain. There is also a need to address the challenges by adopting the life course perspective not limiting the risk factors only to occupational exposures. Further research on neck and shoulder pain development among workers should also use longitudinal designs (i.e. observation or intervention) as cross-sectional studies add little new evidence. There is a need for explaining rather than describing the relationships between risk factors for neck and shoulder pain. The design and analyses of future research must therefore aim to mirror the complexity of the development of neck and shoulder pain.

CONCLUSIONS

The results from this dissertation confirmed findings from earlier studies that mechanical workload, such as working with arms elevated pose an increased risk of neck and shoulder pain. The dissertation however possibly also adds some new knowledge as these findings concerns a young working population with minimal earlier work exposure. It has been suggested that factors at the beginning of working life have important delayed consequences, especially for workers with musculoskeletal disorders. The findings from the current dissertation show that young adults report increased neck and shoulder pain in their transition to working life. Young workers are also more likely to be exposed to poor working conditions than older workers, and it is evident that studying populations early in the working career may be important to identify work-related risk factors associated with musculoskeletal pain.

Even though the level of neck and shoulder pain was relatively low in this cohort of young workers, it was evident that the neck and shoulder pain increases during the transition from technical school to working life. The findings suggests that mechanical workload is a risk factor already early in working life indicating the need for attention on the work environment among young workers particularly those ending up with manual work. An earlier study has shown that training in working techniques among hairdressers can reduce working hours with arms elevated (Veiersted et al., 2008). If technical schools integrate health and safety issues in the curricula from an early age young people will be aware of the potential risks at work. An earlier study highlights that the development of neck and shoulder pain in workers are multifactorial (Côté et al., 2008). Our findings also indicate this, showing that gender, muscle tension habits and trapezius muscle activity at work was associated with neck and shoulder pain. Prevention strategies only targeting specific risk factors (e.g. mechanical workload) are therefore less likely to reduce the incidence of neck and shoulder pain. An review from 2008 showed no scientific evidence that the implementation of prevention programs aimed to modifying workstations and workers postures reduced the incidence of neck pain (Côté et al., 2008). The implementation of interventions should therefore reflect the multiple risk factors.

One of the challenges when studying a young population is the need of a long follow-up period as the outcome may only develop after many years. The low level of pain severity may suggest that there is a need for a longer follow-up time than what we had in our study. Even

though there were a significant increase of neck and shoulder pain over time in our cohort a longer follow-up period may have captured a larger variability in the outcome thus making comparisons easier. In our study we have a unique possibility to reconnect with the participants as we have the approvals from The Norwegian Data Protection Authority and The Regional Committee for Medical Research Ethics. Our plan is to track the participants after approximately 10 years in an attempt to shed light on the changes in musculoskeletal pain, work-related exposure and working status and further illuminate the possible risk factors for development of neck and shoulder pain. It is also our plan to continue analyzing on the data collected from this cohort and continue analyzing the descriptive results presented in the section on supplementary results in this dissertation.

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